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ABSTRACT

The history, problems, arguments, and controversy concerning power created by nuclear fission are outlined. The purpose of the booklet is to present unbiased information for the layman in understandable language in order to improve the quality of national debate over nuclear power. Information for the booklet was gathered from journals, government reports, private institutions, academicians, and government commissions. The eight-chapter document discusses incidents leading to the current controversy over nuclear power, the formation of the UN Atomic Energy Commission, the Atomic Energy Act of 1946, and the establishment of the U.S. Atomic Energy Commission, which has exclusive control over production, ownership, and use of fissionable materials in the United States. Methods are outlined for measuring and judging risks when energy sources are compared. The safety factors of low and high level radiation, the necessity for improving safety systems, and reform needs in licensing, operations, and emergency plans are also discussed. A "short course" in nuclear reactors describes light water, breeder, and alternative reactors. Rising construction costs, financial constraints, and cheaper alternatives for utilities companies are presented as major economic factors. The final chapters consider the nuclear fuel cycle for uranium and plutonium, weapons proliferation, and nuclear terrorism. (KC)

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A NUCLEAR POWER PRIMER: ISSUES FOR CITIZENS

By

Marjorie Beane

U.S. DEPARTMENT OF EDUCATION
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Preface

How safe is nuclear power? Are there less risky energy alternatives? To what degree will nuclear power grow or decline? What forms will it take? Will we have it—or not have it—by decision or by default?

This publication does not resolve such questions. What it does attempt to do is to offer citizens a reliable reading on the state of the art, pro and con arguments on controversial issues and a framework for thinking through their own answers.

A Nuclear Power Primer focuses on the form of nuclear power now in use in all operating nuclear power plants in the world: *the generating of electricity from the steam heat created by nuclear fission.* Fission power is based on the splitting of atoms. This technology, evolved from the atomic bomb research that began the nuclear age, could endure from a few decades to centuries. The uncertainties about those time spans are part of the discussions that follow. (The *Primer* does not discuss the feasibility of generating electricity at some future time by nuclear fusion—the joining of two atoms to form a third.)

The League of Women Voters Education Fund undertook this publication because its board has been acutely aware of the need to raise the quality of the national debate over nuclear power, which is highly charged. It is the hope of the LWVEF board that by offering unbiased information in language accessible to lay persons and thereby enlarging the numbers of citizens who are able to participate in the debate, the *Primer* will move the debate to a better level of information, trust and mutual respect.

It has not been an easy task. It *has* been undertaken in good faith and executed with extraordinary care. Both in planning it and executing it, the LWVEF has been helped by friends from academia, from industry, from many scientific specialties and from the world of citizen activists, all of whom have been exceptionally generous in giving advice and making careful critiques of successive drafts.

The principal author is Marjorie Beane, director of the LWVEF Nuclear Energy Education Program. Paul Hayes of the *Milwaukee Journal* also contributed to the manuscript. □

1
Introduction

Americans are now living at the peak of the petroleum age, and, if predictions of conservative geophysicists are correct, we are perforce groping our way to another energy era. As an earlier LWVEF publication put it: "Societies and cultures not only are in the business of inventing new ways to use energy but, in the manner of a feedback system, are constantly being changed in turn by their uses of energy."[1] This age is no exception.

What *is* exceptional is that we can, if we will, make deliberate choices about the energy base of the coming era, in full awareness that when we choose a source or a mix of sources, we are choosing among values. We are defining not just our energy future but in some degree our social, our political and our economic institutions as well.

After World War II, many predicted confidently that America's energy future would be built on the nuclear know-how acquired in developing the atomic bomb. The nation's first commercial nuclear power plant began contributing to our voracious and growing appetite for electricity in 1957. That Shippingport, PA reactor was financed in part by federal funds. The U.S. Atomic Energy Commission (AEC) was trying to launch private industry into nuclear power—a goal of the federal government since the end of World War II.

For years, the program seemed to be going well, although the anti-nuclear movement was gaining momentum by the early seventies. At the end of 1978, 71 licensed commercial nuclear power reactors were providing 12.5 percent of all the electricity being used in the United States. Shippingport's capacity of 90 MW (megawatts) was far outdistanced by newer plants with capacities up to 1,150 MW. Except for a serious fire at Brown's Ferry nuclear reactor (Tennessee) in 1976, the industry's safety record was good.

A majority of U.S. citizens favored the program, as demonstrated time after time in public opinion polls and occasional state referenda. And the Arab-induced petroleum squeeze seemed at first to reinforce the idea that nuclear power was the great hope for the nation's energy future. But as the decade of the eighties begins, this vision has blurred and receded. What happened, to change prospects so abruptly?

In order to answer that question, it is necessary to step back a decade and scan the evolving energy scene, to highlight the converging forces

that have brought the nuclear industry to its present uncertain state.

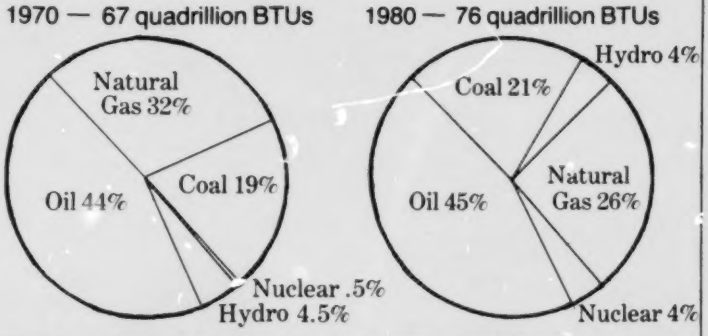
In 1970, oil provided 44 percent of our energy, natural gas 32 percent, coal 19 percent, hydropower 4.5 percent and nuclear power .5 percent (Figure 1). And U.S. production filled most of the demand for the first two. But it was in 1970 that domestic oil and natural gas production hit a peak; since then, demand for energy has continued to grow—though at a slower rate than before. To fill the gap between declining domestic supply and growing demand, we have relied increasingly on imported oil. Despite the temporary interruption of the Arab oil embargo and despite multiplying OPEC (oil-producing exporting countries) prices, U.S. oil imports grew from 23 percent of total U.S. oil supply in 1970 to about 48 percent by 1977.

While oil imports have since declined to about 40 percent of total oil use, we are nonetheless still depending on other countries for almost a quarter of all our energy. Two facts, agreed upon by energy experts, make that statistic one of striking importance.

- No matter what policy reforms may take place, the United States will never again produce enough oil and natural gas from conventional sources to meet current, let alone growing, demand. Even world oil production might peak around the year 2000.
- Once those two severe limits on supply become the base line for planning, it becomes evident that it is none too soon to start designing a national energy future based on something other than oil.

This was the context in which the major debates began, in the 1970s, over U.S. alternatives: synthetic fuels from coal and oil shale, gas from tight sands and geopressured zones, energy conservation, solar energy, nuclear energy, coal and other energy forms. One strongly promoted strategy to reduce dependence on foreign oil was to substitute uranium

Figure 1: Energy Consumption in the United States



Source: Energy Information Administration: 1980 Annual Report to Congress, Volume Two Data

and coal for oil in fueling the production of electricity, with the prospect of reducing U.S. oil consumption by roughly 10 percent.

Many recommended using uranium over coal, citing its environmental advantages and the favorable economics experienced up to that time. They pointed out that nuclear power plants do not emit the tons of sulfur oxides, particulates or carbon dioxide associated with burning coal. Though nuclear plants, like coal-fired plants, require strip-mining and deep-mining for fuel, with all the environmental and social consequences entailed, the scale is much smaller because it takes so much less uranium than coal to generate the same amount of electricity.

To all appearances, nuclear power was arriving on the scene just in time, as oil and gas, the traditional work-horse fuels, were getting harder to find, more expensive to buy and more uncertain to import. In addition, the environmental consequences of mining and burning coal were proving to be very serious and very expensive and difficult to correct.

Some people backed nuclear power not for the long haul but as a vitally necessary transitional source of energy: that is, to help get the industrial and industrializing world off its oil habit and into a future fueled by some essentially inexhaustible and environmentally benign energy source, such as solar power or nuclear fusion. Others saw nuclear power—through the development of a breeder reactor that would greatly extend uranium supplies—as a long-term option itself, a source of power sufficient for thousands of years.

Yet by 1980 the nuclear industry was in virtual paralysis. Utilities were not ordering any new reactors; they had cancelled about 50 previous orders and they had deferred construction of over 100 plants for five to ten years. To compound the problem, in several cases they were having trouble getting licenses to operate new reactors already built.

What had happened? What had gone wrong? Powerful winds of change had blown across the American—indeed, the worldwide—landscape. Some changes were linked to major shifts in U.S. demand for electrical power in general; others had to do with nuclear power in particular.

■ The Arab oil embargo of 1973 and subsequent OPEC actions had many effects, two of which bore with special weight on the nuclear power industry. On the face of it, quintupled oil prices might have been expected to be a big shot in the arm for nuclear (as well as coal-fired) electricity generation. Instead, when the steep increases in oil prices further accelerated already rampant inflation, all energy costs, not just the price of petroleum products, rose and kept on rising. In a classic marketplace adjustment, demand, especially for electricity, fell in only five short years from a long-time annual growth rate of seven percent (which meant a doubling every ten years) to a rate of less than half that. This precipitate change was bound to make electrical utility companies reconsider their plans for new plant construction of all kinds.

■ In this period of rethinking, nuclear power fared worse than coal. Why? For one thing, nuclear plants, though cheaper to operate, are more expensive to build: they are complex, they have tough safety requirements, and interest costs are high during the long construction and licensing period. As inflation worsened and safety requirements increased, the capital costs of these plants skyrocketed—to several billion dollars each. With demand and therefore revenues declining, utilities had trouble raising the huge sums required to finance nuclear plants; they began to think smaller and to risk less.

Besides suffering from the impacts of inflation and OPEC-bred alterations in energy supply, demand and costs, the nuclear power industry has some special problems of its own.

■ Questions of nuclear reactor safety and regulatory effectiveness, never completely resolved, flared up in 1979 with the accident at the Three Mile Island nuclear power plant near Harrisburg, PA, an accident gravely serious in its political and economic impact.

■ A major piece is missing in the nuclear fuel cycle. There is still no permanent waste disposal system, in part for technical but primarily for political reasons. This serious gap in the cycle has contributed to a lack of confidence on the part of both investors and the public.

■ The 1981 Israeli bombing of an Iraqi nuclear research reactor focused world attention once more on the potential link between nuclear power and weapons proliferation. Although Iraq insisted that its reactor was part of a program to develop nuclear power and other peaceful uses of nuclear energy, Israel claimed that Iraq planned to use the facility to produce plutonium for nuclear weapons.

■ The future of the breeder reactor remains clouded. While Congress has appropriated funds for the construction of a demonstration plant (the Clinch River breeder reactor), it has so far been unwilling to subsidize the reprocessing of commercial spent fuel, a necessary step in the fuel cycle if breeders become part of the nuclear system.

■ Two- to five-year delays in building nuclear power plants have added millions of dollars to the costs of each plant.

■ The public continues to be concerned about the health effects of small releases of radioactivity to the environment from uranium mines, mills and other parts of the nuclear fuel cycle.

■ Nuclear power has faced ever more militant and sophisticated public opposition along a broad front ranging from environmental advocates who raise specific arguments against specific plants to groups or individuals who associate nuclear power with a value system with which they disagree.

This publication traces the evolutionary history of nuclear power and examines these problems, summarizing the major arguments opponents present, on controversial points. It also lays out some questions that are larger that the sum of the separate but interrelated conflicts

over safety, economics and health and environmental risk.

- Do we have a choice about whether to use nuclear power?
- Are there adequate alternatives, both in the short and the long run?
- If nuclear power is part of the nation's energy mix, what kinds of social institutions will be required to safeguard it and assure that the technology is always used in the public interest?

The lack of adequate forums wherein to debate these issues has contributed to the impasse that now prevails regarding nuclear power. Licensing hearings provide one of the few arenas for public discussion of nuclear power. But these hearings focus on specific environmental and safety issues. They do not address broad-gauge questions about America's energy future: about growth, about the kind of world Americans want for themselves and succeeding generations, about the political institutions they want to keep or change in order to make that world possible.

The convergence of forces that have slowed energy growth and reduced the need for new power plant construction offers citizens a time to think through what they really want life to be like in the next century and what part, if any, they want nuclear power to play in that future. □

A roller-coaster ride for the nuclear power industry

Whether it is graphed in terms of number of nuclear reactors or megawatts (MW) of electricity-generating capacity, the nuclear power business—from manufacturers of reactor components to installers of reactors to the electric utilities that use the reactors—has had some startling ups and downs. Or rather, more accurately, a startling up and down.

The upswing occurred in the 1960s and to a lesser extent the early 1970s, when the demand for electricity was steadily climbing. U.S. commitment to nuclear power peaked in 1975 at 236,000 MW: 236 plants in all, of which 62 were in operation and 174 others were either under construction, ordered or announced.

The first sign of a downswing came when Consumers Power Company of Michigan cancelled its order for a twin-unit 2,300-MW nuclear plant in 1974. Soon after, other utilities started to delay or cancel construction of nuclear units.

From 1974 to 1980, about 77,000 MW of nuclear capacity were cancelled. (Faltering demand has also caused utilities to cancel more than 10,000 MW of coal-fired capacity.) In October 1981, U.S. commitment to nuclear power stood at 163,000 MW: 171 plants, of which 78 were in operation and 77 had construction permits (but had not necessarily been started), 2 had construction permits pending and 14 had been ordered. Nuclear power provided 11 percent of the nation's electricity and about 4 percent of total U.S. energy use.

2
The dawn of a new age

Mankind's successful transition to a new age, the Atomic Age, was ushered in July 16, 1945, before the eyes of a tense group of renowned scientists and military men gathered in the desert lands of New Mexico to witness the first end results of their $2,000,000,000 effort.

This first sentence from the old War Department's news release about the explosion of Trinity, the first atomic bomb, at Alamogordo Air Base, New Mexico, suggests something of the awe that accompanied the birth of the atomic age.

Three weeks later the atomic bomb was exploded twice against Japan. Soon afterward, President Harry S. Truman wrote with prescience about the import of the new technology, when he asked Congress for legislation that would set policy covering the use and development of atomic energy:

"The discovery of the means of releasing atomic energy began a new era in the history of civilization. The scientific and industrial knowledge on which this discovery rests does not relate merely to another weapon. It may someday prove to be more revolutionary in the development of human society than the invention of the wheel, the use of metals or the steam or internal combustion engines."

Some saw from the start, as President Truman did, the potential this new technology carried for changing society. They knew it demanded a new institutional structure to match that potential, one that would channel its beneficial uses without unleashing its destructive power. What was not clear was what kinds of political institutions, domestic and international, were needed.

History

After the end of World War II, the United Nations General Assembly established an international commission "to deal with the problems raised by the discovery of atomic energy." The UN Atomic Energy

Commission (UNAEC) spent three years discussing proposals for the international control of nuclear energy. The most famous one, the Baruch plan, called for an international agency that would own all nuclear materials and facilities and conduct all nuclear operations. The plan would have given all nations access to the benefits of peaceful nuclear energy without allowing them to use this technology for hostile purposes. Neither this nor any other UNAEC plan could muster the needed international consensus.

The United States, which was the sole possessor of a nuclear capacity between 1945 and 1949, participated in these international discussions but at the same time set about creating an institutional framework for the domestic development and use of nuclear technology. As a first step, Congress passed the Atomic Energy Act of 1946, which took control of nuclear technology out of the hands of the military and placed it under the regulation of a unique five-member civilian commission, the Atomic Energy Commission (AEC). This regulatory body had unprecedented power and autonomy, with exclusive control over the production, ownership and use of fissionable materials for both military and peaceful purposes. The AEC was also charged with safeguarding the secrets of atomic energy, which at the time were known only to a few select American scientists.

Because of the cloak of national security that enveloped the work of the AEC and the technical complexity of the subject, other government officials and the general public in particular had an extremely difficult time getting a handle on the activities of this powerful agency. The main body to which AEC was accountable was a new congressional committee also formed by the Atomic Energy Act, the Joint Committee on Atomic Energy (JCAE). A close partnership soon evolved, however, between the AEC and the JCAE, and the committee tended to encourage the work of the AEC rather than to check on it.

The AEC spent its first years mostly on military applications of nuclear energy, but in 1954 Congress amended the Atomic Energy Act to permit privately owned utility companies and manufacturers to build, operate and own nuclear facilities, based on AEC research and information and subject to AEC licensing and regulation. Most private companies and utilities did not leap at the opportunity; nuclear power was new and still evolving, and industry preferred to leave the development risks to government. But the AEC (and the JCAE, as well), believing that national prestige and economic security required that the United States forge ahead, began promoting the technology it was responsible for regulating.

The AEC relied primarily on two carrots—government assistance programs and reports on the potential of nuclear power plants as clean, safe and cheap sources of energy. Such reports were accepted almost uncritically, even though their cost estimates were based primarily on experimental and/or extrapolated data. The JCAE for its part shepherded through Congress in 1957 a statute (see box: The Price-

Anderson Act) that limited the liability of the nuclear industry to $560 million in the case of a catastrophic power plant accident.

AEC and JCAE efforts brought results. In 1963, Jersey Central Power and Light Company bought a nuclear plant without government assistance, calling it the cheapest available source of electricity. This landmark decision signaled the start of commercial nuclear power development; within four years, U.S. utilities had ordered 75 nuclear power plants with a total generating capacity of over 45,000 MW.

Lost in the general optimism about the potential for nuclear power was the fact that it was, indeed, potential. Many of the plants ordered were still experimental—they would be much larger, and more complex than anything in operation. In addition, many questions about reactor safety, waste disposal and other aspects of nuclear power had surfaced but not been resolved. Yet, once the AEC had won the industry over, it

The Price-Anderson Act

This amendment to the Atomic Energy Act has two purposes: to ensure that the public would be compensated in the case of a nuclear accident and to protect the nuclear industry from a potential accident liability so large that it would threaten the future of nuclear power. When first enacted, the Price-Anderson Act was generally regarded as a necessary antecedent to the development of commercial nuclear power, but it has since evolved into a major source of controversy.

First passed in 1957 and renewed for 10 years in 1966 and 1975, Price-Anderson sets up a three-tier "no-fault" system of insurance against nuclear accidents, with a current $560-million ceiling. The first layer a utility buys from private insurance firms; it is currently $160 million. The second layer is a pool fund into which each utility would have to put up to $5 million per operating nuclear reactor for compensation in case of a major accident where damages exceed $160 million. As of 1981, there are 78 operating reactors, which means that utilities would pay up to $390 million in such "retroactive assessments." Until there are enough reactors to generate $400 million in this second-layer pool fund to meet the $560-million ceiling, the government would contribute the third layer—the money necessary to make up the difference.

In exchange for this limited liability, the Price-Anderson Act imposes what is known as "strict liability" on the utility involved in an accident that is determined by the NRC to be an "extraordinary nuclear occurrence" (ENO). Strict liability means that the utility must waive normal legal defenses against paying claims (up to the ceiling), relieving victims from proving the utility was negligent or "at fault." The public need only show that their losses were caused by the ENO to recover damages under this provision.

Many nuclear critics have vehemently opposed the Price-

dropped much of its own research on light water reactor (LWR) technology and moved on to what it saw as the "next step" in nuclear development—advanced nuclear reactor design, such as the liquid metal fast breeder reactor (see box: Nuclear Reactors: A Short Course).

The AEC found itself swamped by its own successful sales job, ill prepared to regulate the burgeoning industry. Many of its experienced staff left for higher-paying jobs in private industry, and the agency could not process the license applications that began to pour in. By 1967, the AEC had a backlog of 31 unreviewed license applications.

By the early 1970s, the AEC was beseiged with complaints from all sides. The industry and the JCAE were distressed by the licensing morass. Then, in a 1971 case, the court sharply criticized the commission for its slowness in complying with the new National Environmental Policy Act (NEPA). That same year, the commission was embarrassed

Anderson Act for several reasons.

- By not making the nuclear industry assume the full costs of a major nuclear accident, the act introduces an indirect subsidy or bias for nuclear power, keeping the price of nuclear electricity artificially low.
- Removing nuclear power from the normal market forces for liability reduces the industry's incentive to ensure plant safety.
- The $560 million ceiling is much too low for an accident that, according to government estimates, could cause damages totaling billions of dollars. Thus, without additional federal assistance, victims of a major nuclear accident might get as little as three cents of compensation for every dollar lost.

Many nuclear advocates stress that this act protects the public interest by spelling out the rights of those damaged by nuclear accidents, simplifying the procedures for recovering losses and providing an immediate pool of money. They maintain that if damages run higher than the maximum it would be a national catastrophe that would warrant government assistance to the victims. They also maintain that without Price-Anderson, a utility involved in a major nuclear accident could easily go bankrupt, in which case the victims of the accident might receive much less than $560 million. Most of all, however, they point to the nuclear industry's excellent safety record; it has had to pay only about $4 million in public claims for damages from nuclear facilities (although a $25-million lawsuit is still pending from TMI). Since there has not been a single ENO to call into play the full provision of the act, they dismiss charges of subsidies as unwarranted and dire claims of uncompensated losses as speculative.

Though Price-Anderson does not expire until 1987, Congress has already started a reevaluation and plans to hold public hearings on the level of liability and other issues over the next several years.

when test results on the emergency core cooling system deviated significantly from predictions, adding to growing public doubts about nuclear reactor safety.

The public started to raise its voice. People wanted more information about decisions relating to nuclear power development and more of a chance to participate in those decisions. But the AEC, with its background of secrecy and accountability to only a select few, was poorly equipped to respond to such demands. Gradually, opposition to nuclear power evolved from localized, site-specific protests to a sophisticated national movement that assailed the AEC for its "conflict of interest" in simultaneously promoting and regulating nuclear power.

Today's Institutions

Congress tried to allay public distrust of both nuclear power development and nuclear power regulation by abolishing the AEC (and the JCAE) and dividing its functions between two new agencies. The Energy Reorganization Act of 1974 assigned responsibility for nuclear research and development to the Energy Research and Development Administration (ERDA), which was absorbed into the Department of Energy (DOE) in 1977. Responsibility for regulating the nuclear industry was assigned to the Nuclear Regulatory Commission (NRC), a five-member civilian board appointed by the President.

The new NRC found that it had inherited a lot of the AEC's old problems. Torn between industry's complaints about strangulation by regulation and public fears over safety, the NRC has attempted to improve safety regulation of operating plants, open up the process to public input, and speed up licensing, with very limited success on all three fronts.

But the severest test of the NRC's performance—and that of the nuclear power industry as well—began at 36 seconds after 4 a.m., March 28, 1979, when an electric pump shut down on an island in the Susquehanna River a few miles downstream from Harrisburg, PA. The pump failure was the first of a cascading sequence of events that has been perceived as the worst accident ever at a nuclear power plant.

For almost a week, the outcome was in doubt. Would there be a massive radiation release? Would the reactor melt down? What was a meltdown? Pregnant women and children were advised to leave the area. Schools were closed. Thousands of nearby residents left their jobs and homes and drove out of the area for a few days. Offsetting some of the exodus was a reverse flow of humanity—nuclear technicians from private companies and the government, federal and state bureaucrats and the international press. Before the accident ended, President and Mrs. Carter had arrived to alleviate public fear and tension. By the end of the week, Three Mile Island (TMI) had gained its place in the history of the twentieth century as a watershed event.

TMI prompted the nation to reconsider the role of nuclear power in our society. In particular, it underscored some fundamental questions about our institutions and their capabilities to manage and regulate nuclear power: Can the federal government regulate nuclear power effectively and respond aptly in times of emergency? Or is nuclear power just too complex and dangerous for some utilities to manage? Are new management and regulatory institutions for nuclear power needed?

President Carter appointed the Kemeny Commission and the NRC commissioned the law firm of Rogovin, Stern and Huge to investigate the causes and consequences of the TMI accident and to recommend ways to avoid such accidents in the future.

Both groups' reports were very critical of the Nuclear Regulatory Commission, calling it poorly managed and agreeing on these major points.

- A "promotional philosophy" left over from AEC days tended to overshadow the commission's concern for public safety.
- The collegial set-up of the commission was incapable of providing the strong managerial direction and overriding commitment to public safety that was needed.
- The President should restructure the NRC as an independent executive agency headed by a single administrator with direct control over staff and resources and with a mandate to concentrate on safe operation of nuclear reactors.

Some interest groups viewed this recommendation with alarm, arguing that having a single adminstrator would give that person too much power and claiming that the agency's management problems could be solved by less drastic reorganization. President Carter's 1979 reorganization order seemed to accept this point of view. It did not dissolve the NRC's collegial structure, but it did invest the chairman with greater powers, particularly over agency staff and in emergency situations. Carter also established a presidential commission, the Nuclear Safety Oversight Committee, to monitor and evaluate the NRC's work in nuclear reactor safety.

Public doubts after TMI about the efficacy of federal oversight were equaled by severe doubts about utilities' management capabilities. The Rogovin report found a "wide spectrum" of capability and warned that "some utilities, because of their limited size, limited technical staffs or limited capital, simply will not be able to meet the increased demands we think the Three Mile Island accident demonstrates must be made upon them by the NRC," for a technology that is "more dangerous, more sophisticated and more demanding of advanced management, maintenance and quality control"[1] than the traditional energy technologies.

Some individuals have proposed a drastic reform, whereby the federal government would construct and operate all nuclear reactors,

just as it controls all enrichment, reprocessing and high-level waste disposal facilities. They reason that federal control would have several advantages over private utilities in ensuring public safety.

- The government would not worry about the cost of safety measures.
- It could more easily and quickly standardize reactor operations.
- It could more effectively assimilate information on safety-related incidents.

Critics of this alternative point to past accidents at government-owned facilities and cite the self-interest a private corporation has in making sure that nothing goes wrong. The Rogovin report recommended a middle road: let larger utilities with greater technical and financial resources continue to run their nuclear plants but establish a public corporation or industry-wide consortium to manage and operate nuclear plants for utilities judged by the NRC to lack the requisite managerial sophistication.

The debate over the need for unique institutional arrangements for nuclear power was, of course, under way well before TMI. As early as the 1960s, Alvin Weinberg (former director of Oak Ridge National Laboratory and current Director of the Institute for Energy Analysis, Oak Ridge Associated Universities) proposed forming a "nuclear priesthood" to safeguard nuclear power. He still maintains that the safe use of nuclear power requires a cadre of technically elite and uncommonly qualified and dedicated managers, similar to the military "priesthood" we now rely upon to maintain and, if necessary, use nuclear weapons. Weinberg suggests that such personnel could manage "nuclear parks"—a cluster of nuclear reactors and support facilities (such as reprocessing and waste disposal) sited together in remote locations. The parks, Weinberg argues, would gather nuclear expertise in a few specific places, reduce the danger to the population from nuclear accidents, particularly by minimizing transportation of nuclear materials, and give nuclear operations the special institutional longevity needed to keep dangerous nuclear materials from being released into the environment in future years.

Others disagree. David Lilienthal, the first chairman of the Atomic Energy Commission, spoke against the nuclear park idea, when it was proposed, for two reasons: remote nuclear facilities would be inefficient and, more important, we need to "demystify" nuclear power by making the lay population more familiar with it, not hand it over to a technical elite.

To evaluate the merits of these different institutional approaches, one needs to understand the types of risks nuclear power poses to society and the steps taken by the NRC and utilities to ensure public safety. The next two chapters outline those risks and the safety systems used to minimize them. □

3
Risk assessment: Comparing energy sources

Life entails risks. There is some danger in almost every activity we undertake—driving a car to work, smoking a cigarette or jogging for exercise. What is being debated in society over and over again is not whether risks shall exist nor even whether risks shall be tolerated, but which risks are acceptable and which are not.

The question of acceptable risk lies at the heart of the nuclear power controversy. Many believe that nuclear energy entails too many dangers to society to be pursued any further; others contend that the risks of doing without nuclear power are even greater. This debate has spawned a number of attempts to analyze and compare objectively the dangers of nuclear power vis a vis other energy sources. This burgeoning new discipline, which can be applied to many other technologies, is called "risk assessment."

Measuring risks

Risk assessment is determining the probability that an individual, a group or society as a whole will experience a measurable adverse effect as a result of the existence of a hazard. There are four stages to assessing the risks associated with energy sources.

1. Identify the different hazards each source presents: What risks arise from extraction and processing? from transportation and storage? from using the source to produce another fuel (e.g. to turn coal into liquid fuels) or to produce electricity? from disposing of waste? and finally from end use?

2. Estimate the magnitude of each risk (e.g., tons of pollutants discharged): How does it impact or stress the immediate environment (e.g., changes in surrounding air quality)? How the environment responds (e.g., expected deaths and cases of disease, damage to land, fisheries and other natural resources)?

3. Evaluate the severity of the damages resulting from each risk: Is the damage irreversible? Is it concentrated or dispersed?

4. Estimate the cost of the damages to society.

While this process appears very straightforward, it is an extraordinarily difficult task. Complete information on which to base the assessment is simply not available for most energy technologies. Despite these limitations, scientists have attempted some comparisons.

Resources for the Future, in *Energy in America's Future*, estimated that the following fatalities would result from supplying energy for one year: .8 to 14 for a coal-fired electricity plant; .2 to 3 for a nuclear power plant; and .2 to 1 fatality for solar home heating.[1]

Herbert Inhaber, a former adviser for the Canadian Atomic Energy Control Board, has calculated the risk of energy sources in terms of worker-days lost (days that individuals could not work because of injury, illness or death attributable to the production and use of an energy source). He found that the total worker-days lost per MW each year over the lifetime of an energy system will range between 100 and 3,000 for coal, between 100 and 120 for solar space heating, between 1 and 3 for nuclear power. He concluded that solar and other nonconventional technologies have risks somewhat comparable to coal and oil because of the large amount of materials they require, the risk associated with back-up energy (assumed to be coal, nuclear or natural gas), and the risks associated with energy storage.[2]

Both studies suggest that the risks associated with nuclear power are comparable to or less than those associated with other energy technologies. Critics, however, point to some major flaws in these and other risk analyses.

- Most risk analyses do not include increased energy-efficiency measures, a major alternative to both coal and nuclear power.

- They are based on incomplete health data. For instance, the great bulk of the health effects that appear in occupational statistics are injuries, and these occupational illnesses typically account for only five percent of the total worker-days lost.[3] Yet occupational exposure to toxic substances at low concentrations may produce over a period of time additional illnesses that are never recorded as job related. Even fewer figures are available on the health effects of small quantities of pollutants on the general public.

- Certain health risks are better known than others and thus may skew the overall risk figures. It is fairly easy, for example, to project worker injuries and deaths during construction. Since manufacture and installation for renewable energy systems are more materials- and labor-intensive than for conventional technologies, the Inhaber study showed *worker* health risks for renewables that were as great as for coal. When it comes to *public* health risks, however, which are harder to quantify and trace, renewables would probably fare better than coal, if

data were available.

■ Occupational and public health risks are often lumped together to obtain total damages to health, a practice some scientists find highly objectionable. They point out that occupational risks are assumed voluntarily, at least in part, in exchange for the benefits of a job, while risks incurred by the public in the course of energy production and use are very different in that they are far less a matter of individual choices.[4]

■ Most quantitative risk assessments focus primarily on health effects, without taking account of important environmental and sociopolitical risks. While difficult if not impossible to quantify, these risks pose some of the gravest and least tractable threats to society.

The burning of coal and petroleum-based fuels presents two of the most significant environmental risks. These fuels release large quantities of carbon dioxide (CO_2) raising atmospheric levels of this substance, which plays a key role in climate determination. Assuming continued growth in the use of fossil fuels, some scientists project that increasing CO_2 levels could cause a perceptible increase in average global temperature by 2030, with massive environmental, social and economic effects from polar melt and other shifts in climate conditions.[5]

These fuels also release other chemicals that interact in the atmosphere to form acid rain, which according to many scientists has already caused extensive property damage—for example, corrosion of buildings—and destroyed or damaged life in lakes and other ecosystems throughout the world. New pollution controls on coal plants will significantly help reduce this risk.

In comparison, routine operation of nuclear power plants poses fewer and less severe direct environmental risks. While a catastrophic accident at a nuclear facility could result in severe ecological damage and thousands of deaths, some experts believe the greatest risk associated with nuclear power is sociopolitical: an augmented chance of nuclear war, through the use of the technology and materials associated with this energy source to make nuclear weapons (see Chapter 7: Proliferation: The Weapons Connection).[6] Scientists seem to be divided, however, on how close a connection actually exists between nuclear power development and the threat of nuclear hostilities.[7] Some argue that any assessments of the risk of war should weigh the risk of *not* developing nuclear power—a choice they believe could lead to energy shortages that in turn would cause regional wars (most likely involving conventional rather than nuclear weapons) over energy supplies. In either case, decisions about nuclear power have direct implications for world peace and regional stability.

Another sociopolitical risk associated with nuclar power is one inherent in all large-scale energy systems: the operation and control of these systems are necessarily centralized and out of the reach of the

ordinary citizen. Those who favor numerous self-sufficient energy systems at the household and neighborhood level argue that these decentralized systems would be more flexible and responsive to local needs and less susceptible to interruption. Supporters of large-scale energy systems counter that our electrical and gas-distribution systems are working well today and that decentralized systems are an untested alternative for a country the size of the United States.

Risk assessment, therefore, is a very inexact and incomplete science. The value of this type of analysis is that it can help give background information to policy makers who must decide whether risks associated with a particular energy source are acceptable.

Judging risks

Even if scientists could appraise and quantify all risks, the acceptability of those risks is a social and political judgment, not a scientific one. Each of us, alone or in concert, constantly makes decisions to opt for or decline a particular risk.

William Lowrance of Harvard University has identified the following factors that individuals take into consideration in evaluating risks:[8]

Risk assumed voluntarily **Risk borne involuntarily**
Individuals are usually more willing to accept voluntary risks, such as smoking and driving, than involuntary risks such as industrial air pollution.

Effect immediate **Effect delayed**
People tend to be more concerned about the immediate effect of a risk than about chronic (long-range) effects. The chance of injury or death today is more frightening to most people than the chance of dying of cancer 30 years from now.

No alternatives available **Many alternatives available**
If no practical alternatives are in sight, people seem to accept a risk, perhaps grudgingly or fatalistically; witness those who live in polluted industrial centers in order to be close to their jobs.

Risk known with certainty **Risk not known**
Risks that are familiar, such as motor vehicle fatalities, seem to cause less revulsion and concern than strange, new or unfamilar risks such as radiation exposure.

Exposure is an essential **Exposure is a luxury**
Individuals are more willing to give up luxuries, such as cosmetics, that pose health risks than "necessities," such as aspirin.

Encountered occupationally **Encountered nonoccupationally**
Traditionally, people have been willing to assume greater risk on the job than at home or in their community. The assumption is that people get paid for taking certain risks.

Common hazard **"Dread" hazard**
People seem resigned to the recurrence of some accidents such as auto collisions and house fires. While they find these accidents regrettable or anguishing, their response to these events can be distinguished from the sort of inordinate dread or horror that might attend news of the destruction caused by a tornado or of sickness from a silent invisible beam of radiation.

Affects average people **Affects especially sensitive people**
The U.S. government has tried to reduce certain pollutants to levels that don't adversely affect public health. However, people more sensitive to these pollutants generally have to assume greater risks than the average person.

Will be used as intended **Likely to be misused**
Misuse of machines and other products is one of the most important causes of accidents. If the probability of misusing a product is high, society is less likely to accept the risk associated with that product.

Consequences reversible **Consequences irreversible**
People are less likely to accept a risk whose consequences are irreversible. This was an important consideration in the decision in the United States to ban certain pesticides which, once released into the environment, spread irretrievably through air and water and persist for many years.

Describing risks in terms of these considerations can help clarify the nature of the controversy over a product or a technology. This is how Lowrance described the hazards associated with nuclear power:

Nuclear power plants are thought to be essential by those who believe that the alternative ways of generating power will not meet energy demands. For the general public, the risks are inescapable once these expensive plants are in operation. What the risks really are is quite controversial. The risks will be both to those who work in the plants and to the general public. Effects will be both immediate, in the event of a catastrophic accident, and delayed, with any radiation exposures. There is a possibility, even if slight, of misuse such as sabotage. Both the radiation hazards and the unlikely-but-horrible explosion hazards carry overtones of dread.[9]

The news media influence public understanding of risks and the intensity of concern over them. In general, sensational events such as airplane crashes make good "stories" and thus tend to get more coverage than less dramatic but more probable hazards, for example, such common illnesses as diabetes. As a result, public concern over certain dramatic events may be out of proportion to the overall risks these events pose to society. A recent study of nuclear energy news coverage on television between 1968 and 1979 concludes that the media have encouraged people to fear it out of proportion to its risks.[10]

Risk decisions are rarely made on the basis of a single factor. Risks

are weighed against benefits, and the combined risks and benefits of one choice are weighed against alternatives. For example, people who support nuclear power generally believe that it will provide necessary benefits—electricity at reasonable prices—that cannot be provided by less risky alternatives.

When policy makers attempt to formalize this process, it is called "risk-benefit" analysis: quantifying as many benefits and risks associated with a technology as possible and then calculating the balance or optimum for the situation. For example, they may assign a dollar cost to the harm that might be done persons and things, then weigh that cost against the economic benefits that a technology or product may tender to the rest of society. A major problem with this approach is that it is difficult, if not impossible, to put a price tag on human life, the beauty of surroundings and other intangibles. Like the risk-assessment process based on probabilities described earlier, risk-benefit analysis is a primitive art at best. It can help identify the issues and establish grounds for rational debate, but it cannot offer a solution.

Neither technique takes into account the *distribution* of risks and benefits of a public policy decision. Who will be exposed to the risks? Will those who benefit also be the ones who are at risk? It is possible to get objective answers to these questions, but, in the end, decisions about the distribution of risks and benefits are political. This being the case, public officials generally make such decisions after consulting not only with the scientific community but also with their constituents and with special interest groups. They may ask for scholarly studies on the impact of technologies and products in society and hold hearings to solicit information and viewpoints from the public. Some jurisdictions give citizens a chance to vote on a particular technology through a referendum (some of them binding, some advisory). For example, California, Maine and other states have held public referenda on whether to construct or operate nuclear power plants.

Citizens' insistence on having a voice in deciding to spread the use of a product or a technology has grown in recent years for several reasons. For one thing, as people have become less vulnerable to diseases and other *natural* hazards, they have become more concerned about reducing the risks from man-made hazards. For another, people better understand the environmental and social impacts of large-scale technology, and at the same time they know that the complexity and scale of modern society robs individuals of the power to estimate, appraise and reduce their own risks.

Has our society become too preoccupied with reducing technological risks? Some people think so. They point out that it was willingness to accept risks in the past that made this country a world innovator and industrial leader, and they characterize many citizen demands for risk reduction as totally unrealistic. Others contend that

such an interpretation of history is misleading. They point out that in the past the people who had the power to decide to take a risk often did not have to experience the risk: the millowner lived and worked well away from the noxious vapors that the millworkers had to breathe. They argue that society has changed and that now those who would incur the risk should have a say in whether to do so or not.

In sum, energy systems have different types of risks, many of which are not really comparable. How can you compare the hazards of acid precipitation with those of nuclear war? Nor can most of these risks be easily quantified. Thus, any evaluation of risks will inevitably involve value judgments. Scientists can provide information on the potential impacts of some risks, but in the end it is the public that will have to determine which risks are preferable, from which energy sources, and at what cost.

Because nothing can be absolutely free of risk, nothing can be said to be absolutely safe. There are degrees of risk; consequently, there are degrees of safety. The next chapter will take up the safety questions surrounding nuclear power. □

4
Safety first: Reducing risks

How safe is nuclear power? This complex question has to be broken into several parts.

- Will long-term human exposure to very small routine releases of radioactivity from the nuclear industry result in increased numbers of cancers, genetic diseases or degenerative diseases in the future?
- Can nuclear facilities—not just power reactors, but other parts of the nuclear system—be designed, built and operated in ways that protect the public from sudden massive releases of radioactive materials?
- Can government and industry regulate nuclear power adequately to ensure public safety?

The sections that follow take up these questions and examine them in considerable detail.

Low-level radiation: Routine operations

The controversy over the health effects of low-level radiation persists because it is virtually impossible to detect immediately any measurable harm to humans at very low levels of exposure. This leaves open the question of whether *any* radiation exposure, no matter how small, will take its toll years later in cancers, leukemias or genetic effects.

People are exposed daily to low levels of radiation from natural sources (cosmic rays from outer space; radioactive materials present in the earth) and man-made sources (medical applications, such as X rays; fallout from nuclear testing; consumer goods such as color televisions). This ionizing radiation is of three kinds—alpha, beta and gamma radiation. While they differ greatly from one another in their penetrating power, all may damage or kill living cells. The most feared types of cell damage lead to cancer and genetic mutations.

That radiation can cause cancer or genetic mutation is not ques-

tioned. What is questioned is the relationship between the dose and the number of resulting cancers or mutations — particularly when doses are below one rem.* The time between exposure and effect can be long. It may take 10 to 15 years for cancer to appear and several generations for genetic damage. For both cancer and genetic mutations there are other possible causes (chemical carcinogens, for example)—a fact that confuses the issue.

Since the effects of very low doses are not known with certainty, the official radiation exposure limits have been based on the *linear nonthreshold hypothesis*. The phrase is more difficult to master than the two assumptions that underlie it: first, that there is no threshold below which radiation is not harmful; second, that the extent of harm is in direct proportion to dose.

For years, many scientists have challenged the validity of this hypothesis in relation to cancer. The 1980 report of the National Academy of Sciences' Committee on the Biological Effects of Ionizing Radiation (BEIR) concluded that this hypothesis is likely to *overestimate* the carcinogenic risks of the type of low-level radiation most frequently encountered (gamma).[1] Most members of the committee as well as many other scientists believe that cancer incidence is somewhat lower at low doses than at high doses, in part because body cells may repair themselves more easily at low doses.

Another, though apparently smaller, group of scientists maintains that this hypothesis may *underestimate* the carcinogenic risks of low-level radiation exposure, citing a government study on radiation exposure from the atomic blasts at Hiroshima and Nagasaki, released in 1981, in support of their position. This study found that most cancer caused by these bombs came from gamma rays—not neutron radiation, as had been assumed before. These findings suggest that gamma radiation may be more hazardous than the BEIR report stated. Thus, the controversy over the effects of low-level radiation continues.

This controversy relates to commercial nuclear power in that mining, milling and other parts of the nuclear fuel cycle result in the release of small amounts of radioactivity to the environment. For instance, uranium mill tailings emit radon gas, and nuclear power plants routinely discharge small amounts of radioactive gases and liquid effluents.

Federal standards limit the amount of radiation a member of the general population can receive from all phases of the nuclear fuel cycle to no more than a 25 mrem whole-body dose per year. With the exception of one or two uranium mills, nuclear facilities are in compliance with this standard.[2] The Nuclear Regulatory Commis-

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*rem - a measure of the energy delivered to human tissue from a dose of ionizing radiation. 1 mrem is equal to 1/1000 of a rem.

sion (NRC) has set an even more stringent design objective for nuclear power plants: a person living near the boundary of a nuclear plant should receive a whole-body dose of no more than 5 mrem each year as a result of the operation of the plant. The actual exposure of those living near nuclear power plants operating under routine conditions averages only 1 or 2 mrem per year. (Unplanned releases during the 1979 TMI accident may have exposed some nearby residents to between 40 and 100 mrem.)[3]

Unless citizens live near a nuclear facility, they receive virtually no radiation from the nuclear fuel cycle. Of the approximately 160 mrem of radiation the "average" person living in the United States is exposed to every year, less than one mrem comes from the nuclear fuel cycle. Thus, it is fair to say that normal operations of the nuclear industry contribute very little to the average radiation dose rate of most Americans.

More controversial than public exposure is occupational exposure. Uranium miners, power plant personnel and other workers actually exposed to radition in the nuclear fuel cycle receive an average whole-body dose of 630 mrem a year.[4] Federal standards allow a worker to be exposed to up to 12,000 mrem in a year as long as the average annual dose is less than 5,000 mrem over the worker's lifetime.

For many years, some labor and environmental groups have argued that these standards, which are several hundred times the radiation dose permitted a member of the general public, do not adequately protect workers against potential health risks. They also assert that some individuals incur even higher radiation doses than are allowable because they fail to report their dose accurately or because of the way the dose is measured.

In 1980, after an extensive review of occupational exposure and of existing guidelines, the U.S. Environmental Protection Agency (EPA) concluded that occupational risks from radiation do not appear to be unreasonably high for the average worker; nevertheless, it has proposed reducing the maximum allowed dose in any one year from 12,000 mrem to 5,000 mrem. EPA also plans to take a second look at radon exposure guidelines for mines and miners.

High-level radiation: What risk do nuclear accidents pose to the public?

Each light water reactor (LWR) produces large quantities of highly radioactive material. Should a massive release of this material occur from a power plant, a reprocessing facility or a waste disposal site or

in transit between these facilities, it would exact a high toll on the exposed population. On this point, there is no disagreement. The controversy arises over whether safety systems thus far developed and the regulatory discipline thus far exercised are adequate to keep this intensely radioactive material confined away from vulnerable populations or biological systems for thousands of years.

Nuclear power plants themselves house most of the high-level radioactive materials produced in the commercial nuclear fuel cycle. These materials are contained primarily in the reactor fuel—both fuel in use and spent fuel. Most spent fuel is presently stored at the plant site in special pools of water though some is transported between power plants or to other storage facilities (see Resources: *A Nuclear Waste Primer*).

The main source of this high-level radiation is the radioactive isotopes produced in the fuel during the fission process. Many of these fission products such as strontium-90 and cesium-137 produce high intensity, penetrating radiation and a lot of heat. Since they are also active biologically, they are easily taken up by the human body. Strontium-90 and cesium-137 have half-lives of about 30 years; that is, it takes 30 years for their radioactivity to be reduced by half. Another family of hazardous isotopes created in the reactor is "transuranics"—literally, new elements that are heavier than uranium. Though the particles they emit, unlike the first-mentioned group, are relatively low in penetrating power and heat generation, most are very long lived. For example, plutonium-239 has a half-life of 24,400 years. If transuranic radioactive isotopes were to escape into the environment, they could pose health hazards for generations.

How could these radioactive isotopes escape from a nuclear power plant? It is not a nuclear explosion that is feared, because neither uranium-235 nor plutonium is present in an LWR reactor in sufficient concentration or in the proper geometry to create a runaway chain reaction. The danger is that a reactor core could lose its cooling water through a pipe break or other mishap, overheat and melt through the building and into the ground, where radioactive fission products could enter the groundwater and eventually the atmosphere. Another possible scenario is that a gas or steam explosion in the reactor would fracture the building, releasing radioactivity directly to the atmosphere.

To prevent just such an accident, a nuclear plant has a series of safety barriers. (For a refresher in pursuing the outline of LWR safety features, see box: Nuclear Reactors: A Short Course.)

1. The first line of protection is the cladding, the metal cylinder around the fuel. This cladding, which traps and holds the radioactive materials produced in the uranium fuel pellets, is made of metals, such as zirconium, that can withstand high temperatures.

2. The second barrier consists of the reactor vessel and, for pres-

surized LWRs, the closed reactor coolant system loop. The steel pressure vessel is about eight inches thick and is surrounded by concrete and steel shields several feet thick, which absorb radiation and neutrons emitted from the reactor core.

3. Finally, all this is set inside the containment building, a steel reinforced concrete structure several feet thick. These buildings are designed to withstand tornadoes, direct collisions from light aircraft, and earthquakes.

4. In addition to these physical barriers, a nuclear power plant has redundant and diverse safety features. Each of its major systems has an automatic back-up system to replace it in the event of a failure. This strategy is known as "defense in depth." For example, in a loss-of-coolant accident (LOCA)—that is, an accident in which the reactor's primary cooling system fails—the emergency core cooling system (ECCS) is designed to use existing plant equipment automatically to ensure that cooling water covers the core.

To date, these safety barriers and systems have worked remarkably well. A full-scale meltdown has never occurred. When there was LOCA at Three Mile Island Unit II in 1979, the ECCS did work, though when operators turned it off prematurely the fuel core was damaged. A small hydrogen gas explosion (not the large bubble that received so much media attention) also took place in the containment building, but this structure was not breached. At Browns Ferry in 1975 an electric cable fire in one unit disabled parts of the ECCS and other safety systems, but the reactor kept on functioning properly, so the back-up systems were not needed. In these, the only two major tests of the safety systems of commercial nuclear plants to date, no major high-level radiation was released.

Even so, these accidents did reveal some deficiencies.

- First, the very combination of equipment failures and human errors that led to both accidents had been clearly identified before the accidents, yet the safety problems were ignored or lost in bureaucratic red tape. This failure to learn from past experience was identified by the Kemeny Commission as a key problem in those organizations responsible for nuclear safety (see Chapter 2, p. 15).
- Another safety problem that surfaced was poor training of nuclear power plant personnel.
- Both accidents also pointed up flaws in nuclear power plant design and instrumentation.
- The TMI accident also suggested that regulators and industry have been so preoccupied with large-break accidents, involving the break of a huge pipe carrying cooling water to nuclear reactors, that the less dramatic accidents involving a combination of minor equipment failures have received short shrift. Since small accidents are likely to occur much more often than the huge accidents, the Kemeny

Commission called for more extensive and thorough study of them..

Improving safety systems

In response to TMI, the nuclear industry has made changes in power plant equipment and has also established new research and management organizations. In 1979, the industry created the Nuclear Safety Analysis Center (NSAC) to study safety problems—in large part through a study of plant accidents or equipment malfunctions—and to devise solutions and distribute this information to nuclear utilities. The industry also established an Institute for Nuclear Power Operation (INPO), charged with establishing "benchmarks of excellence" in the management and operation of nuclear power plants. INPO will conduct periodic evaluations of operating practices at nuclear plants, in order to help utilities meet high standards, and will offer new improved training programs for nuclear operators.

While the nuclear industry believes its initiatives have significantly improved plant safety, the Union of Concerned Scientists (UCS) and other nuclear critics disagree. They charge that industry has so far implemented very few design and operational changes. USC also believes that there is no way to assess whether INPO and NSAC are doing what they claim since many of their activities and findings are kept secret from the public.

Regardless of how effective industry initiatives are, the NRC must still resolve a set of *generic* safety problems—those problems the NRC has identified (some as long as a decade ago) as being common to all operating reactors or to all plants manufactured by a particular company. Among the most significant: 1) the ability of a plant's safety systems to operate effectively in the event of a fire or under the severe conditions of high temperature, pressure and radiation existing during an accident; 2) the effectiveness of the emergency core cooling systems; 3) possible damage to safety equipment from "turbine missiles" in the event that the main turbine generator accidentally breaks apart; and 4) the vulnerability of plants to sabotage.

A generic safety problem that has received renewed interest of late is the reactor vessel's material toughness. Engineers have long known that radiation from the reactor core causes steel to become brittle over the years. Recent data, however, suggest that the rate of embrittlement may be greater than originally anticipated when the nuclear reactors were built. Some engineers fear that older reactor vessels could crack under certain temperature and pressure conditions, leading to a loss of coolant and a fuel meltdown. The NRC is taking a fresh look at this problem.

Nuclear critics claim that many of these generic safety problems exist because the government and industry pushed the development of commercial plants too fast during the 1960s and 1970s. They

How safe is safe enough?

Given the present design of most nuclear power plants, just what is the probability that a major accident will release a significant amount of radioactive material? That was the subject of a study on reactor safety commissioned by the NRC and directed by Professor Norman Rasmussen of the Massachusetts Institute of Technology.[5] Issued in 1975, this study—WASH 1400—estimated the probabilities that various combinations of plant equipment and safety procedures might fail; that all these different possible events could lead to a core meltdown or another serious accident; and that such accidents would expose nearby populations to possible health risks.

WASH 1400 predicted that the chance of a core meltdown is one in 20,000 per reactor per year, but that the chance of a core meltdown causing deaths or injuries to the public is much less—one chance in three million per reactor per year. The consequences would depend on how much radioactive material got outside the reactor, on weather conditions, on how many people lived in the affected area and on what public safety measures were employed.

The worst case accident in WASH 1400 was predicted to kill some 3,000 people immediately by acute radiation sickness, kill some 45,000 others over a period of years by radiation-induced cancers and require decontamination of several thousand square miles. But the yearly probability of such an accident's occurring in any one reactor was predicted as being only one chance in 200 million. Thus, in a world containing 200 operating reactors, the report predicts the chances of a worst-case accident to be one in a million in a given year.

Critics attacked the study for failing to address all the health and environmental effects of radiation releases. They argued that WASH 1400 greatly understated the risks of nuclear power because it could neither identify all possible accident sequences nor deal with the adequacy of reactor design and, even more important, could not deal with certain types of human error. The TMI and Browns Ferry accidents, which occurred after WASH 1400 was completed, do suggest that the role of human error is important. TMI is, after all, classified as a very serious accident with a correspondingly very low probability of occurring. But it did occur.

In 1978 a group of scientists chaired by Professor Harold Lewis of

contend that not enough time was taken to test reactor ideas and designs and that safety considerations were sacrificed to economics. In particular, they feel that the size of nuclear plants outstripped engineering experience, with average plant size under construction growing from 200 MW in 1960 to 1,000 MW in 1970.

In response, the nuclear industry points out that despite rapid

the University of California, Santa Barbara, conducted an independent review of WASH 1400 for the NRC.[6] Their conclusion supported the critics: that while the study was a substantial advance over previous attempts to estimate the risks of the nuclear power option, it understated the uncertainties surrounding the probability estimates of reactor accidents. In particular, they noted, the numerical estimates of overall risks in WASH 1400's Executive Summary were not reliable. Consequently, in January 1979, the NRC decided that the WASH 1400 estimates should not be used uncritically to justify regulatory or policy decisions in the future as they have been in the past.

That puts government back to square one, without a credible estimate of the overall risk to human health and safety presented by nuclear reactors. NRC officials still believe strongly, however, that the probability of a nuclear power plant accident causing deaths or injuries to the public is very small. They hold that, while the Rasmussen data may not be good enough by itself to make statements about the overall safety of nuclear power, they are good enough to be useful in verifying that a specific nuclear power plant is safe.

Of course, the root question in the controversy is "How safe is safe enough?" The NRC is now developing safety goals that will define more clearly the degree of safety needed to protect public health and property. The goals will probably include quantitative limits on the frequency of accidents or individual risk of death as well as qualitative objectives such as improved operator training or remote siting. In establishing such goals, NRC will be examining not only the risks of nuclear power but those of alternative energy sources and other social endeavors.

While the nuclear industry is generally supportive of NRC efforts, the Natural Resources Defense Council, the Union of Concerned Scientists and other groups have some grave reservations about whether quantitative safety goals are verifiable. They contend that assessing risk on a probabilities basis as NRC plans to do is far too imprecise to form the basis of regulatory decisions. They also question whether NRC will be able to make the risks associated with nuclear power "consistent" with the risks of other energy technologies since these risks vary dramatically in nature and are very difficult to quantify.

development (which is in any case not unique) the safety record of large nuclear plants is equal to or greater than that of other technologies. They also contend that most generic safety problems are for the most part resolved and that only minior aspects of these issues will require further research or study. They argue that managerial and procedural problems at NRC are preventing a timely

disposition of these issues.

Industry is not alone in criticizing NRC's handling of generic safety issues. The Kemeny and Rogovin reports (see Chapter 2, p.15) pointed out that NRC has resolved only two generic safety issues in the past decade and has not implemented these solutions. The Rogovin report also observed that NRC has little incentive to resolve generic safety problems promptly since it can continue to license individual plants, reasoning that the probability of a serious accident's happening before a generic problem is resolved is low.

Regulatory reform

Resolving nuclear hardware and design problems will improve nuclear power plant safety. But equally important is having a strong regulatory program to ensure the implementation of technical fixes and to enable the public to cope with any future nuclear accidents. The Kemeny and Rogovin reports urged the NRC to make reforms in three major areas of regulation: the licensing of new plants, safe operation of existing plants and plans for dealing with accidents and other emergencies at nuclear power facilities. Each of these areas has important ramifications for public safety.

Licensing

The licensing process now in place pleases almost no one. Industry claims that it's an unbearable drag on the growth of nuclear power. Others protest that it is not nearly strict enough to protect public welfare and safety. A utility wishing to add a nuclear power plant to its system must get two licenses from the NRC, one to build it and one to operate it.

The NRC grants a *construction* permit, after a mandatory public hearing, once it determines that a nuclear power plant can be built at a proposed site without endangering public health and safety or severely impacting the environment. The NRC issues an *operating* license if the completed plant meets all safety regulations and is in compliance with NEPA.

Nuclear power proponents from industry and government claim that the dual-licensing approach draws the process out needlessly, by allowing duplicative arguments over the same points. They also claim that current licensing procedures are so unpredictable both in time and content and so protracted as to make it virtually impossible for the nuclear industry to function.

A study by the Atomic Industrial Forum (the nuclear industry trade association) found that the licensing process and required design changes add about three years and $260 to $450 million to the cost of a nuclear power plant. (That means about $40 per year on the average family's electric bill over the plant's 30-year life-span.)[7] The

time can be significantly longer in individual cases. Extended delays such as those experienced at the Seabrook and Diablo Canyon plants can make nuclear power a very risky investment in the eyes of financial institutions. The report concludes that nuclear power's continued survival depends on getting a licensing process with "reasonable and predictable" time frames.

Nuclear critics point out that other industry and government studies show that construction and procurement problems, lower electric demand forecasts and financial constraints are greater sources of delay than the licensing process.[8] They maintain that in cases where licensing delays have occurred, intervenors were raising legitimate and important safety questions. For example, the safety implications of new seismic data delayed the licensing of Diablo Canyon Unit One (the plant is located near major earthquake faults).

Some citizen activists do, however, question the value of the dual licensing approach on different grounds. They argue that at the initial hearing, on the construction permit, there is not enough information to evaluate the safety and environmental impacts of the proposed plant and that by the time of the hearing (if one is held), for the license to operate, the plant is a *fait accompli*. Many people on both sides of the nuclear power fence agree that the licensing proceedings are long, expensive endeavors, mired in legalities rather than geared towards exchanging information on technical points and tending to promote combativeness rather than compromise. Significant support, including that of the Kemeny and Rogovin reports, is building in favor of a one-stage licensing process.

Other citizen activists are firmly convinced that two safety checkpoints are essential. They cite the very sketchiness of the preliminary designs at the construction permit stage as reason enough for a second full review of the safety issue.

In contention also is the scope of the licensing process, particularly the tendency of the NRC to concentrate on the potential for single, large-scale failures rather than on the more common small-scale problems and on human factors such as operator training and utility management that also affect safety (see "Operation" below). Citizen activists also argue that they should be allowed to raise broad questions about the desirability of nuclear power in the energy mix, rather than be forced to be site specific.

Following TMI, the NRC put an 18-month moratorium on issuing new licenses, to allow time for review. In that period, it made several changes in its licensing procedures, including stronger safety regulations, to address some of the equipment and operator deficiencies mentioned earlier, and more authority for its Atomic Safety and Licensing Board. The ASLB can now raise questions not raised by any of the parties to the licensing proceedings.

Many of these changes drew fire from the nuclear industry, which

claimed that the new rules would further lengthen the licensing process, making an already intolerable situation worse. Some now say their fears were justified. In the two-and-a-half years since TMI, NRC has granted only six full or partial operating licenses and no construction permits.

In response to industry concerns, the Reagan administration has instructed NRC to step up the licensing pace. In March 1981, Acting NRC Chairman Joseph Hendrie outlined a plan to meet this goal: shorten NRC safety and environmental review periods; cut the public hearing process from 18 to 8 months; and, with the end of the one-year licensing moratorium, shift NRC staff from other programs to licensing. Hendrie also asked for legislation that would allow the NRC to issue "interim operating licenses" (through 1983) before the conclusion of public hearings on a plant and to issue license amendments that pose "no significant hazard" to public health and safety without holding public hearings prior to the ruling. In addition, NRC has proposed eliminating nonsafety issues, such as the utility's financial status, from licensing procedures.

The NRC and its supporters maintain that these changes will not impair public participation and a full consideration of safety issues. Many citizen activists disagree. They claim that proposed rule changes would severely curtail citizen participation and that interim licenses prior to public hearings would make a mockery of the whole licensing process. Finally, they believe that NRC has unfairly blamed the public—intervenors—for licensing delays; they point instead to the NRC staff's slowness in reviewing applications and preparing testimony as the most important source of delay. This slowness is in turn attributable in some cases to the utility's tardiness in furnishing information and answering questions.

Who knows what the long-term effects of accelerating the licensing process would be? The nuclear industry hopes that some changes will inspire investors and that, in a year or two, utilities will begin to order new nuclear reactors, something they are not doing at the moment.

NRC Commissioner Victor Gilinsky and others warn that, by putting too much pressure on the NRC to speed up licensing, industry may be doing itself a disservice. They point out that NRC work on safety issues fell far behind schedule during 1980 because of staff shifts to licensing. They also emphasize that one of the reasons for emerging safety problems in existing plants is that these plants went through the licensing system at a time (the early 1970s) when there was great pressure to crank out licenses.

Operation

Once nuclear plants are licensed, the NRC and utilities are responsible for their safe operation. Both the Kemeny and Rogovin

reports were very critical of NRC's regulation and utilities' management of existing plants. The NRC, they charged, had lost sight of the forest for the trees by concentrating on issuing numerous safety regulations rather than developing safety goals. Other problems identified were:

- deficient training programs for plant personnel;
- poor communication between NRC field inspectors and headquarters; and
- an ineffective penalty program.

The Union of Concerned Scientists has also criticized NRC for not demanding retrofitting of existing plants with safety equipment required in new plants or at least considering whether each existing plant incorporates an equivalent level of protection.

However, the nuclear industry complains that too much retrofitting is required already on partially constructed plants—changes that are very expensive and may even interfere with overall safety systems design, thus actually detracting from reactor safety.

After TMI, the NRC moved to correct some of the failures of its enforcement program. With its licensing moratorium in force, the agency temporarily transferred staff from licensing into enforcement and redoubled efforts to evaluate long-standing safety questions. It also increased fines and penalties for infractions of regulations and revamped the inspection program and other procedures to enhance attention to safety questions. Although the NRC's inspection program still falls short of its goals, according to a 1981 House Government Operation Committee report, the agency has re-tilted staffing back toward licensing new plants, in keeping with the new priority on speeding up the licensing process.

Emergency planning

The TMI accident illustrated another problem area for nuclear regulatory and management institutions: emergency preparedness and emergency response. At the time of the accident, the state emergency preparedness plan for the TMI plant did not meet the NRC guidelines; the county had a sketchy plan; and none of the local communities had any emergency plans at all. The plans that did exist were not coordinated: they contained different accident classifications and different procedures for notifying government authorities.

Consequently, when an emergency did arise, federal, state and local agencies were ill prepared: confusion over "who's in charge"... conflicting signals and reports from different sources of authority... no head agency or chief spokesperson directing the federal government's actions...a five-member collegial set-up of the NRC ill suited to crisis management...three conflicting "authoritative recommendations" from the NRC regarding evacuation...lack of com-

munication and coordination between the national, state and local governments, which stymied planning and decision making, particularly over the crucial issue of evacuation.

Industry's performance was likewise flawed. Technical experts who had experience with nuclear accidents couldn't reach plant personnel to help them bring the problems under control. The utility tended to downplay the seriousness of the accident, which led to suspicions of a "cover-up," compounded by handling of news reporters' questions.

In the wake of TMI, government and industry have made improvements in emergency preparedness. The NRC requires utilities to develop more extensive evacuation plans for approximately 10 miles surrounding their plants before receiving an operating license. The NRC also requires the state and localities to draw up plans for a nuclear emergency. President Carter created a new agency, the Federal Emergency Management Agency (FEMA), to coordinate federal response to disaster, including radiological accidents. FEMA is currently helping states and localities draft their own management plans to respond to nuclear accidents.

Utilities operating nuclear plants now have rooms with monitoring and communication equipment outside the reactor control rooms to manage future emergencies; with this equipment, utilities can directly contact and get assistance from the plant's vendor, the NRC and the industry crisis management organ, the Nuclear Safety Analysis Center.

On the other hand, many utilities have not met the NRC's July 1,1981 deadline for having basic warning systems (e.g., sirens) in place. Emergency plans developed so far vary greatly in their quality and detail, and many do not effectively spell out what must be done by whom in an emergency. Thus, it's still not clear whether institutions will be better able to cope with any future nuclear accident.

Because safety is a highly relative condition that can change from time to time and be judged differently in different contexts, there are no definitive answers to the questions posed at the beginning of this chapter. As knowledge of nuclear risks has evolved, so have standards of safety. For example, radiation doses thought safe 40 years ago are now deemed too risky. Some of the safety equipment installed in the first nuclear plants is now obsolete. Thus, safety evaluation and standard setting is an edifice, the construction of which is never completed. Safety decisions are never absolute. When they are made, they should be the products of the best scientific data and experience available; they should also reflect public expectations and values. □

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Nuclear reactors: A short course

Light Water Reactors (LWRs)

The LWR uses a uranium oxide fuel consisting of roughly 3 percent uranium-235 and 97 percent uranium-238. The fissioning (splitting) of uranium atoms (primarily uranium-235) in the reactor releases large amounts of energy and one or more neutrons. These neutrons hit other uranium atoms and cause more fissions, creating a chain reaction.

The energy released in this chain reaction fits into a conventional process for making electricity: it heats water and produces steam, which turns a turbine shaft connected to a generator. The generator converts the mechanical turbine energy into electric energy that can be distributed over an electric power grid. The overall conversion process is nuclear energy ⧫ thermal energy ⧫ mechanical energy ⧫ electrical energy.

The important reactor components are the *core*, consisting of fuel rods, the control rods and the moderator; the *heat exchange system*, which both cools the reactor and transfers the heat produced to the steam system; and the *turbine generator*, which is similar to those in steam power plants burning coal, oil or gas.

The core is made up of several hundred fuel assemblies, each of which is a bundle of several hundred fuel rods—long, thin metal cylinders (about ten feet long and one-half inch thick) filled with fuel pellets. Interspersed between the fuel assemblies are control rods. These rods, containing materials that capture neutrons, can be moved in and out of the core to regulate the rate of the fission process and, as a result, how much power a plant produces. When the control rods are all inserted into the core, fission stops.

Water circulating between the fuel rods and between the assemblies serves as the moderator, i.e., the agent that slows neutrons, thereby increasing their chances of hitting other fuel atoms and continuing the chain reaction. It also has two other functions: it keeps the temperature of the fuel rods well below that at which the core materials would begin to melt, and it carries the heat energy out of the core and into the heat exchanger.

It is in the details of the heat exchange system that the two main LWR types differ. In the more widely used of the two types, the Pressurized Water Reactor (PWR), the water circulating through the core is under high pressure (2,250 lbs. per square inch) and reaches a relatively high temperature (300°C or about 600°F) without boiling. The PWR requires a separate heat exchanger loop that extracts the heat from the primary system and uses it to

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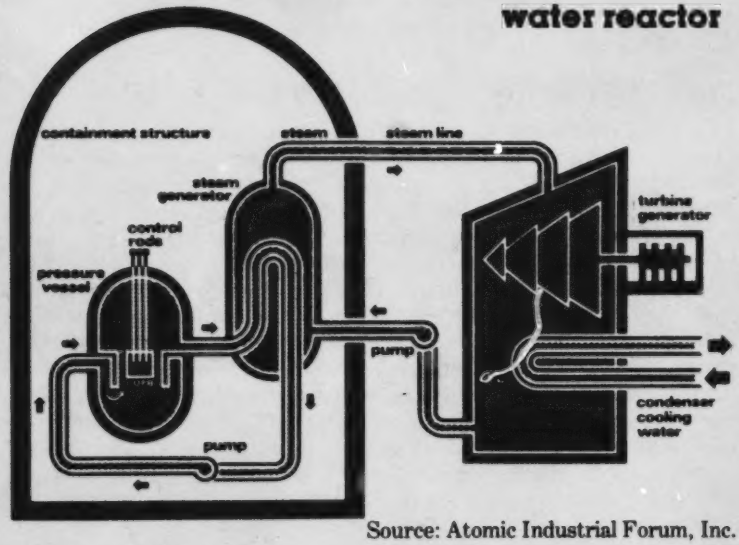
Figure 2: Pressurized water reactor



Source: Atomic Industrial Forum, Inc.

generate steam. Only steam from the secondary loop gets to the turbine (see Figure 2).

In the Boiling Water Reactor (BWR), the operating pressure is lower. Boiling and the formation of steam occur within the reactor vessel, and this steam goes directly to the turbine (see Figure 3). In both PWRs and BWRs, the nuclear reactor and the primary coolant systems are attached to a large, steel pressure vessel, which is housed in a concrete containment building.

After each year of operation, one-third of the reactor fuel must be replaced. At this point, the spent fuel contains roughly 1 percent uranium-235 and 1 percent plutonium (a new element created from reactions of neutrons with uranium-238). Both the uranium-235 and the plutonium can be separated out through reprocessing, then refabricated into fresh fuel elements. Thus LWRs both *consume* fuel in the course of producing power and *produce* fuel. The ratio of fuel created to fuel consumed is called the conversion ratio. The ratio for most LWRs is .6—that is, about six new fuel atoms are produced for each ten consumed.

Breeder Reactors

If a reactor can make fissionable isotopes faster than it uses them up, it is known as a breeder, i.e., it "breeds" more fuel than it consumes. A breeder reactor uses different combinations of fission-

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able materials and fertile materials. (Fertile materials are those capable of being converted to fissionable materials.)

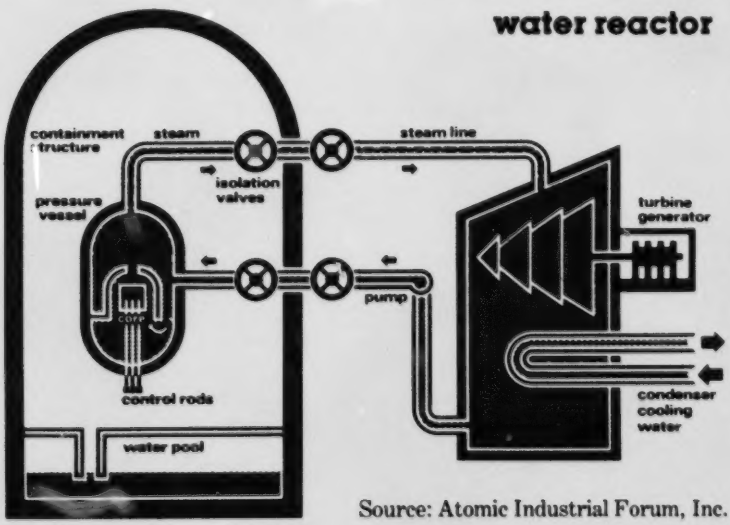
The combination with the greatest commercial potential is fissionable plutonium and fertile uranium-238—the mix used in the Liquid Metal Fast Breeder Reactor (LMFBR).

In the LMFBR (see Figure 4), the fuel core contains a mixture of plutonium and uranium oxides. It is surrounded by a blanket of natural or depleted uranium-238. This ensures that some of the neutrons produced during the fission process will hit and be absorbed by fertile uranium-238 atoms, converting these atoms into plutonium. The fuel conversion ratio for the LMFBR is 1.1 to 1.3, that is, for each 10 fissionable atoms used up in the reactor, 11 to 13 new fissionable atoms are formed.

While LWRs operate with low-energy neutrons, the LMFBR uses high-energy—"fast"—neutrons; therefore, unlike an LWR, an LMFBR does not use a moderator to slow neutrons. Instead, liquid sodium, a nonmoderating material, flows through the core extracting the useful heat.

Because sodium is made intensely radioactive by the enormous number of neutrons present in the reactor core, it must be kept isolated from the rest of the power plant. Consequently, the LMFBR has a primary sodium loop that exchanges heat with a secondary loop of sodium. The heat from the secondary loop is used to generate steam for electricity in a third loop.

Figure 3: Boiling water reactor



Source: Atomic Industrial Forum, Inc.

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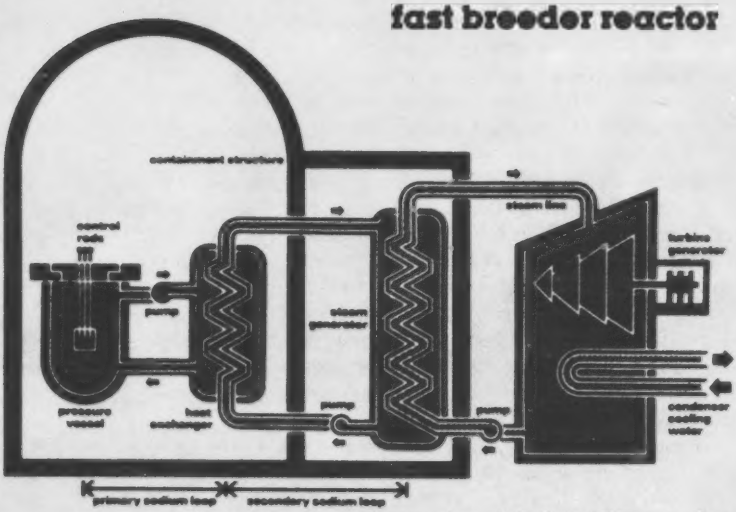
Figure 4: Liquid metal fast breeder reactor



Source: Atomic Industrial Forum, Inc.

Sodium is an excellent heat-transfer fluid, and the LMFBR can operate at high temperature (around 500°C) and low pressure (1450psi). It can achieve a thermal efficiency of about 40 percent compared to 32 percent for an LWR.

However, sodium does have a major disadvantage. It is a highly volatile metal: at high temperature, on contact with air, it burns; on contact with water, it creates hydrogen and explodes. Since the whole object of the process is to transfer heat from the sodium to the water in the breeder's steam generator, the LMFBR needs much more elaborate leak prevention and detection systems than are necessary for LWRs.

Another safety problem is related to the high reactivity of the breeder's core fuel. This fuel is far more enriched than fuel for an LWR, containing from 10-to-30 percent fissionable material versus 3-to-4 percent in an LWR. This means that if breeder fuel was damaged in an accident, it would release more uncontrolled energy more rapidly than LWR fuel. Such an event, classified as a "core disruptive accident," could occur after a meltdown; and, while it would never equal the explosive force of a nuclear weapon, the NRC has required that breeders be designed to cope with a reactor explosion.

In addition, because of its higher plutonium content and because the fuel is exposed in the reactor longer than LWR fuel, there is a

high concentration of fission products in breeder fuel, creating a correspondingly greater potential radiation hazard. This is true particularly during reprocessing, where the dissolving of breeder fuel releases fission products and other highly radioactive wastes. Thus, in the breeder fuel cycle (see Figure 8) more stringent controls of radioactive releases in both normal and accident conditions are required than in the LWR once-through fuel cycle (see Figure 6).

Experimental breeders have been operated in this country since 1951. England, Russia and France have all run pilot or test breeders; France, whose Phoenix (250 MW) has been in operation for several years, is now constructing a 1250 MW Superphoenix. West Germany and Japan are each constructing a 300 MW experimental breeder. The United States is operating a Fast Flux Test Reactor in Richland, Washington, which will be used to develop breeder fuel and other technology and is constructing an experimental LMFBR on the Clinch River in Tennessee.

Alternative Reactors

Canadian deuterium uranium (CANDU) reactor This reactor, now in commercial use in Canada and other countries, operates with natural uranium. The CANDU can use natural uranium because it employs heavy water (the oxide of deuterium, the heavy isotope of hydrogen), which is a more efficient neutron moderator than the water used in LWRs. The reactor requires some 20-percent less uranium than present LWRs; by using slightly enriched uranium (about 1.2 percent uranium-235), it could use 40-percent less uranium.

High temperature gas-cooled reactor (HTGR) Helium is used as the heat transfer medium and graphite as the moderator, allowing HTGRs to run at much hotter temperatures than other reactors and increasing their efficiency. A prototype is operating in Colorado, but there is little commercial interest at present.

Fast-mixed spectrum reactor (FMSR) A variation of breeder reactor technology, the FMSR can be fueled with low-enriched uranium. After a large initial load of uranium, this FMSR and successor reactors would create and burn plutonium in their fuel without any reprocessing, reducing uranium requirements by more than 90 percent. FMSR has been identified as the "most promising" of the advanced concepts, but its technical feasibility has not yet been proved. □

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5 Generating electricity: The economics of the case

An AEC official once commented that nuclear power as a source of electricity would be "too cheap to meter." That prediction illustrates all too well how hard it is to be a prophet. Over the past decade, the cost of building a 1,000 MW nuclear power plant has increased from several hundred million to more than a billion dollars. While the costs of all goods have skyrocketed, the average capital cost of nuclear plants has risen far more than the general rate of inflation. As a result, state regulatory authorities are taking a hard look at the effects of nuclear generation costs on electric bills. They are asking two basic questions: Why the dramatic increase in the cost of nuclear power? Is nuclear power still economically competitive with other energy sources?

Bargain basement prices

In the early and mid-1960s, nuclear reactor manufacturers, notably the General Electric Company and the Westinghouse Electric Corporation, encouraged utilities to order light water reactors (LWRs) by offering "turnkey" contracts to deliver a completed power plant at a fixed price. Utilities bought 17 reactors, with a capacity of 10,000 MW, under this type of contract arrangement.

Since most of these plants experienced large cost overruns, the suppliers lost hundreds of millions of dollars on these contracts, but they did accomplish their main objective: to develop markets for LWRs and build the utilities' confidence in nuclear technology. By 1968, utilities had ordered a total of 62 reactors with a capacity of approximately 50,000 MW.[1]

This nuclear market boom came about despite the fact that the

technology and its operating performance (i.e. reliability, repair and maintenance) were almost untested. In 1965, the first commercial-scale reactor, Dresden 1 (200 MW), located in Illinois, had been operating for only five years, and utilities were ordering much larger reactors—up to 1,000 MW in size—before any intermediate-size units were operating. Furthermore, the impact of the regulatory process on costs was still an unknown, and inflation had not yet taken its full toll. As a result, the final price tags—taking into account design changes, unforeseen operating costs and regulatory delays—for reactors ordered in the late 1960s greatly exceeded the manufacturers' estimates. But on this round, it was the utility—hence, the consumer—and not the supplier that paid. Had manufacturers priced LWRs more realistically from the start, it is unlikely that utilities would have made such a large commitment so quickly to this new technology.

Rising construction costs: The key factors

Nuclear power is not the only energy technology buffeted by inflation, mismanagement and unexpected retrofitting costs. The costs of building coal plants, installing solar collectors and using other energy sources have also increased. But the cost increases for building nuclear plants are astronomical. The percentages run from a few hundred to over 1,000 percent, and the dollars run in the billions. For example, in 1980 the Philadelphia Electric Company raised the estimate for its still unfinished two-unit Limerick plant (1,150 MW) from a 1972 figure of $375 million to $3.1 billion—a jump of more than 725 percent. Why has there been such a dramatic escalation in costs?

Rampant inflation and interest rates

When plant orders were placed in the early 1970s, utilities assumed an inflation rate of about 4 percent a year and interest rates of 3 to 5 percent. But by 1981 the inflation rate had almost tripled, and interest rates, with their geometric effects on the "rent" paid for money, had raced up—as high as 18 percent. Finance charges accounted for 30 to 35 percent of total construction costs—even 50 percent in cases where there were major delays during construction. In short, they actually doubled the total cost of the plant.

Construction and licensing delays

Construction and licensing delays have intensified the effects of inflation on the cost of labor and materials and have caused interest charges to mount.

A 1978 Congressional Budget Office (CBO) study estimated that utilities have experienced an average 10-month delay in obtaining a

construction license. The resolution of safety and environmental problems was the major cause of this delay.

The longest delays, however, have occurred during the actual construction period. These delays have averaged about two years. According to CBO and other studies, declining demand and financing problems were the principal causes. When demand for electricity declined in the mid-seventies, regulators began questioning the need to construct new power plants, complicating utility efforts to raise capital for these projects. As a result, many utilities had to slow down or postpone their construction projects. Other sources of delay included labor strikes, low productivity, late delivery of materials and management problems. CBO found that changes in federal regulation caused only 20 percent of all delays during construction. (Recently, a few utilities have experienced delays in obtaining operating licenses; NRC's post-TMI licensing pause delayed the operation of three reactors for more than a year.)

Both advocates and critics of nuclear power find fault with the CBO study. The Atomic Industrial Forum (AIF) contends that government regulation has been a much greater source of delay than CBO indicated. It believes that shortening the licensing process, in particular, could substantially reduce the overall costs of building a nuclear plant. In contrast, the Union of Concerned Scientists argues that very few utilities have experienced delays because of the licensing process. They contend that a major reason why many nuclear plants are not being completed on time is that most utilities have consistently underestimated lead times.

The impact of delay on consumer costs is considerable. A one-year delay can boost the cost of a nuclear power plant by about $90 million, according to a 1978 NRC report; it could also cost consumers an additional $100 million if utilities have to purchase an alternative source of power in the interim.

Design changes

Design changes (including retrofits) required to improve safety, environmental features and operating reliability increased the real cost (minus the impact of inflation) of nuclear construction between 1971 and 1979 by 100 to 140 percent. This rate of increase in real cost is twice that for the construction of coal plants; it is also much higher than the rate for the construction industry as a whole.[2]

As more nuclear plants came on line during the 1970s and operating experience increased, regulators and the public began to question the adequacy of many safety and environmental features of these plants. The AEC investigated these questions and, in cases where defective equipment was discovered, ordered utilities to make costly improvements.[3] Between 1973 and 1976, for example, the NRC issued approximately 180 new environmental and safety regulations.[4] Furthermore,

manufacturers made design changes on their own initiative to improve operating reliability.

These design changes and the increased size of reactors have more than doubled the amount of material and labor needed to build a nuclear plant over the past decade, significantly adding to construction cost.

Present costs

If a utility decides to build a new nuclear power plant (1,000 MW) and have it operational by 1995, DOE's Energy Information Administration

Calculating generating costs

Utilities divide production costs, as manufacturers do, into fixed costs and variable costs.

Fixed costs, which include plant construction costs plus interest charges on borrowed capital, are stable once incurred. *Variable costs*, which include fuel, wages and material costs incurred in operating and maintaining the plant, fluctuate because they are sensitive both to inflation and to the amount of electricity produced by a plant over a year.

A generating station's total electricity costs are computed by dividing the sum of fixed and variable costs for a certain period of time by the amount of electricity produced during the period. The result is expressed in tenths of a cent, or mills, for each kilowatt-hour of electricity produced and delivered to the nearest point on the utility's distribution network, normally on the plant's grounds.

The relation of the fixed costs to the variable costs determines which of the three types of service, outlined below, each power plant is best suited to provide.

Base-load plants are designed to operate at full capacity for prolonged periods. They generally have high fixed costs and low variable (i.e., operating) costs. Nuclear power plants and large coal-fired units (above 500 MW) fall into this category.

Cycling plants can operate at less than full load without a great loss in efficiency and with flexibility to respond to hourly fluctuations in daily load requirements. Coal-, oil- and gas-fired plants in the 200-600 MW range are used for cycling.

Peaking plants generate electricity a small portion of the time, when maximum or peak generating capacity is needed (for instance, during a heat wave). Relatively small gas- or oil-fired turbine units in the 25-50 MW range are ideal for peak load units.

To optimize production costs, utilities will have a mix of these three types, with base-load plants providing 65-70 pecent of the generating capacity in most cases.

estimates it would cost about $1.59 billion in constant 1980 dollars.* Since the dollar will not remain at its 1980 value over the 12- to 15-year time period it takes to license and construct the plant, allowance must be made for inflation. If the inflation rate were 10 percent per year, for example, the actual cost of a new nuclear plant would be about $5 billion. Other estimates range from $4 to $8 billion per plant.

The capital cost (see box: Calculating Generating Costs) of a new reactor, however, varies widely among different regions of the country. For example, it costs about 15 percent less to build a nuclear plant in the south than in New England. These regional variations stem from differences in site conditions, wage rates, taxes, financing costs, and so on.

Of the total cost of generating electricity from a nuclear power plant, capital costs account for about two-thirds and fuel, operation and maintenance costs account for the other third. Operating costs, like construction costs, have been increasing faster than the general rate of inflation because of new safety and environmental regulations, unanticipated equipment problems, and increases in the number of personnel needed to run a nuclear plant.

Comparing the generating cost of nuclear and coal-fired plants

If a utility needs a new source of **base-load** electricity (see box: Calculating Generating Costs), it has only two realistic options: a coal-fired plant or a nuclear power plant. Figure 5 compares the total costs of generating electricity from these two types of plants for 1980. According to these DOE estimates, nuclear plants generated base-load electricity slightly cheaper on the average than coal-fired plants. Of course, this cost advantage for nuclear does not hold for every region. Nuclear plants are less expensive in the north central region; coal plants are cheaper in the far western (when sited near low-cost coal) and in the southern and the middle Atlantic regions.

Many nuclear critics contend that averaging generating costs from all plants camouflages the rapidly deteriorating economics of nuclear power and that the more significant cost comparison is between *new* coal and nuclear units. A 1979 AIF survey showed that for those units entering service in 1975 and later years, power from nuclear plants was more expensive than power from coal-fired plants.

Charles Komanoff, an independent energy consultant and long-time critic of the nuclear industry, predicts that by the late 1980s electricity

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*This estimate is based on a national average capital cost of $1,585 (constant 1980 dollars) per kilowatt on installed capacity.

Figure 5: National averages of U.S. private and public utility nuclear and coal-fired power plant generating costs for 1980

Cost category	Average unit costs mills per kilowatt-hour	
	Nuclear	Coal
Fuel cost (actual)	4.77	12.69
Operation and maintenance cost (actual)	5.35	2.52
Capital cost (estimated)	13.11	8.13
Total generating cost (estimated)	23.23	23.34

These cost estimates are for a typical LWR pressurized water reactor (over 400 MW) and a coal-fired power plant (over 500 MW), both operating at about 60 percent of their capacity. A mill is a tenth of a cent. A kilowatt-hour is a thousand watts used for an hour.

Source: *UPDATE: Nuclear Power Program Information and Data*, prepared by Office of Coordination and Special Projects, Office of Nuclear Reactor Program, U.S. Department of Energy, May/June 1981, p. 32.

from new nuclear plants will be at least 25 percent more expensive than electricity from new coal plants, with most of the increased costs in nuclear power stemming from new safety regulation. The AIF strongly disagrees with this assessment, arguing that the 1970s was a decade of nuclear regulatory change unlikely to be duplicated in the 1980s. Consequently, the AIF does not anticipate a significant number of new and costly safety requirements.

Komanoff and the AIF also clash on another subject—at what percentage of full capacity each type of plant will operate. No power plant ever operates at full capacity, that is, produces energy all the time. It is periodically shut down for maintenance and repairs. In general, the more expensive a plant, the more it needs to operate, to be cost efficient. Given that the capital costs of a nuclear plant are much higher than for coal, nuclear electricity costs are more sensitive to plant outages.

During the seventies, nuclear plants over 400 MW and coal plants over 500 MW both averaged about 60 percent of capacity.[5] Komanoff's study assumes that improvements being made in newer coal units will enable them to achieve a 70-percent capacity eventually, whereas he sees no similar trend for nuclear power plant performance, because most units are experiencing more mechanical problems than anticipated and are often shut down for repairs. In addition, the new larger nuclear plants over 800 MW are averaging only 55 percent capacity.

The AIF points out that nuclear plants averaged 65 percent of their

capacity in 1977-78 and regards the decrease to 60 percent in 1979-80s as temporary—traceable to TMI-related events. They expect nuclear capacities to return to 65 percent or more and doubt that large coal plants will achieve 70-percent capacity in the near future, given the pollution-control backfitting and upgrading they will have to do.

In sum, when the two types of plants are compared, the average costs of generating electricity are about the same, if all operating plants are included; but if only new operating plants are considered, nuclear power is a more expensive source of electricity than coal. Whether this trend will continue will depend on regulatory activities, equipment performance and other factors.

Financial constraints

In deciding whether to build a nuclear or coal-fired plant, a utility must weigh the separate elements that together produce a generating cost for a particular plant. One important element is initial capital costs.

At present, electric utilities are encountering difficulties in raising funds for new construction projects, because of high interest rates and the inability to recover adequate revenues to meet the inflation-driven costs of construction, fuel and general operations. Thus, many utilities are tending to favor intermediate-sized coal units (450-750 MW) because of their lower initial capital cost and shorter, more predictable construction and licensing lead times.

Utilities get money to build by selling common stock (shares) in their company or by selling bonds (long-term debt). Over the last decade, escalating construction costs, declining demand for electricity and lagging rate relief have lowered the market value of utility stocks. Most utilities must now sell stock at a discount from its book value. As for bonds, because of the utilities' weakened financial condition, the business community now perceives utility projects as more risky than heretofore and thus will buy utility bonds only if they get a higher-than-normal rate of return on their investment.

The accident at TMI Unit 2 further disillusioned investors about utility stocks and bonds, especially for companies operating and/or constructing nuclear projects. The owner of the TMI plant, the General Public Utilities Corporation, was pushed almost to the brink of bankruptcy overnight. The corporation had only $300 million in insurance to cover on-site damage estimated at $1 billion; in addition, it had to buy replacement power to meet customers' needs. Even more devastating was the fact that the NRC would not permit the operation of TMI Unit 1 after the accident. The Pennsylvania and New Jersey State Public Service Commissions then removed this operable reactor and the damaged TMI unit from the rate base, so the utility could not earn a return on these facilities to pay for the cost of money invested in them.

To ease investor concern over the financial risks posed by nuclear

power, the nuclear industry has since set up insurance pools that cover the cost of on-site damage (up to $1 billion) and of replacement power, should another nuclear accident occur. While some investors are still reluctant to buy securities from utilities heavily committed to nuclear power, such insurance efforts have helped stabilize investor concerns. Most financiers are willing to invest in these utilities as long as they receive a high rate of return to compensate for the high perceived risk.

Most utilities, however, aren't earning enough to offer this inducement. Most are earning an average rate of return of 12 to 13 percent—several percent below the ceiling permitted by their state public utility commissions. In comparison, oil and chemical companies are earning 15 to 20 percent. The other financing option is to sell bonds at very high interest rates—15 to 18 percent; but for a regulated utility to borrow money at interest rates higher than its rate of return is not generally a good business practice.

Another problem is that the sums utilities must borrow to construct power plants, especially nuclear plants, are so huge. For example, the two-unit Midland nuclear plant in Michigan will ultimately cost Consumer Power Company about $3 billion, over 50 percent of the utility's existing assets as of the end of 1979. If a utility's ratio of debt to net worth becomes too great, its credit standing will suffer and the value of its stock will further decline.

For these and other reasons, utilities have had to postpone or cancel construction projects. And nuclear power plants have been among the first to be delayed, because of their high initial capital requirements and long lead times over which interest charges are levied.

As a rule, public utilities commissions do not permit utilities to bill customers for a new power plant until it has begun to supply electricity, but some utilities have asked state PUCs for permission to add a Construction Work in Progress (CWIP) surcharge on customer billing, to be used to pay interest on money borrowed to construct a power plant. (At present, many utilities have to borrow money just to pay interest on their debt.) Proponents say that CWIP would hold down future increases in customers' bills because utilities would have already paid part of the capital cost of a new plant before it enters service.

Since interest charges account for about one-third of the total construction costs of a nuclear plant, utilities building these plants are especially anxious to have CWIP. Commonwealth Edison (Illinois) has already been allowed to charge its customers for one nuclear plant still under construction.

But many consumer groups strongly oppose this surcharge, because CWIP shifts the investment risks from stockholders to rate payers; that is, it guarantees that the utility will generate enough income to cover its interest expenses regardless of whether the investment was a wise one. They also believe that current customers should not have to pay higher rates so future customers will have a break. Finally, they point out that

The impact of subsidies

The cost of nuclear electricity would be higher if federal subsidies to the nuclear industry were included in the estimated fixed cost. According to a 1981 DOE study, the U.S. government invested about $14.6 billion (1980 dollars) in the research and development of commercial nuclear power between 1950 and 1979. If billed directly to utilities, this subsidy would raise by about 10 percent the fixed costs on the 160 nuclear plants operating or under construction.

These figures do not take account of future federal subsidies, which could add up to another $10 billion (1980 dollars) by the year 2000 if they continue at past rates. And the reckoning would be substantially higher—closer to $40 billion—if past and projected federal research and development funds for the breeder reactor and nuclear waste management, as well as federal expenditures for military nuclear programs that have benefitted civilian nuclear power, were added in.

The nuclear power industry is not alone, however, in enjoying federal assistance. Fossil fuels—oil, natural gas and coal—have benefitted for years from government subsidies, tax benefits and trade restrictions. For example, a 1980 DOE study estimates that coal has received about $14.3 billion (1980 dollars) in cost incentives and oil over $146 billion (1980 dollars). Of course, coal and oil have much broader uses than just generating electricity, and the percentage of electricity generated by coal is about four times greater than that generated by nuclear power. It could be argued, therefore, that the coal subsidy dollar has produced a much larger benefit to date.

money will be worth less in the future anyway.

Some observers believe that an outmoded regulatory structure is a fundamental problem for utilities. When state PUCs were set up to regulate utilities more than 30 years ago, the cost of electricity was constant or declining. Utilities were a high-growth, low-risk business capable of accepting a low yield. Now electricity demand has waned, costs are rising rapidly, and utilities have become a high-risk venture; yet PUCs have made few policy changes to reflect this new reality. Some economists have recommended either major reforms in PUC operation or complete deregulation of the utility industry. The merits of these ideas are being closely scrutinized by government and industry officials.

Cheaper alternatives for utilities and for the public

Future investment may not be in coal-fired or nuclear power plants. High financing costs, fluctuation in demand, and the long times required

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to build a plant have made large nuclear power and coal plants much less attractive than they were ten years ago when demand was higher.

Some utilities are starting to promote conservation as a low-cost source of new energy, to install equipment designed to decrease demand, and to invest in small-scale generating stations. Southern California Edison, for example, reorganized its capital investment program to accelerate small-scale and renewable resource projects. By 1990, the company expects to generate 30 percent of its new electrical capacity from wind, geothermal, solar, hydro and cogeneration facilities. These alternative diversified energy projects are easier and quicker, although not necessarily cheaper, to build than nuclear or coal plants. For example, it takes two or three years for a windmill or geothermal station to begin service, compared to ten to twelve years for a nuclear plant. Herein lies the financial benefit: money borrowed to pay for construction can be repaid sooner, and this accelerated rate of cash flow makes the business a more attractive investment.

New England Electric has adopted a similar approach. It has about a dozen alternative fuel projects in the works, including two plants that burn solid waste and a low-head (small) hydroelectric generation station. The company is also aggressively promoting conservation. It expects to obviate the need for one 1,000 MW nuclear power plant and to reduce its investment budget by $2.6 billion over the next 15 years.

Other utilities are maintaining a more traditional approach, planning for at least a four-percent growth in electricity demand each year. They believe that too great a reliance on conservation and small-scale technologies could lead to power shortages in the future. In general, these utilities are likely to opt for new coal-fired plants in preference to new nuclear plants as long as coal plants have more predictable licensing environments, shorter construction lead times and lower total costs.

On the average, the nation has a 35-percent surplus of electric generating capacity (twice the recommended reserve margin); thus, most utilities can postpone commitment to new generating facilities for at least a few years. Whether utilities will resume building nuclear power plants will depend on many factors, including the rate of inflation, the costs of financing, the length and uncertainty of the licensing process, how electric rates are calculated (whether CWIP is allowed) and the demand for electricity. Nuclear power will have a difficult time competing economically with other energy sources if inflation and financing costs remain high and electricity demand low. □

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The nuclear fuel cycle

The commercial nuclear power system that exists today in the United States is dominated by one kind of reactor, the light water reactor (LWR), and by a fuel cycle based on once-through uranium use. ("Once-through" means that only fresh uranium oxide fuel is used; spent fuel is being stored until a method of permanent disposal is established.) If this system were the only one available and were not at least gradually improved, a limited uranium supply would bring an end to nuclear power throughout the world sometime in the next century.

But that is a big *if*. Neither long-term use of LWRs nor a once-through fuel cycle was originally contemplated. The AEC expected to shift to two technologies that could extend the nuclear age thousands of years into the future: the *reprocessing of spent fuel* to recover usable uranium and plutonium and a *breeder type of reactor* that would need only small infusions of fresh uranium oxide to keep going indefinitely.

Why hasn't the United States developed this more elaborate system? The answer is a mixture of politics and economics. Reprocessing of some commercial spent fuel did take place in the early 1970s but soon ceased because technical problems made the operation uneconomic. In 1976 and 1977, President Ford and President Carter put reprocessing and the commercialization of the breeder reactor on indefinite hold because—unlike the existing system, which employs uranium fuel in a form that cannot be used for nuclear weapons—the new technologies would both produce and use plutonium, and plutonium is the stuff of which nuclear weapons are made.* Thus, the "plutonium fuel cycle," as it is called, could facilitate the proliferation of nuclear weapons.

In 1981, President Reagan lifted the moratorium on reprocessing of commercial spent fuel and directed government agencies to proceed with the demonstration of the breeder reactor. The economic barrier,

*The fissioning of the uranium fuel in LWRs creates plutonium that in turn fissions and helps generate energy, but if this plutonium is never separated from the fuel by reprocessing, it never appears in a form accessible for nuclear weapons.

however, remains. Private industry in the United States has no immediate plans to build either kind of facility because of the huge investment costs required and the availability of cheaper alternatives.

Before laying out the advantages and disadvantages of the two different nuclear power systems, a brief review of the two fuel cycles is in order.

Once-through uranium fuel cycle

The main ingredient of the once-through uranium fuel cycle (Figure 6) is uranium-235, a naturally occurring substance that can sustain a chain reaction. Uranium-235 is found as a rare component of uranium at a richness of only .7 percent, the rest being chiefly uranium-238 (99.3 percent).

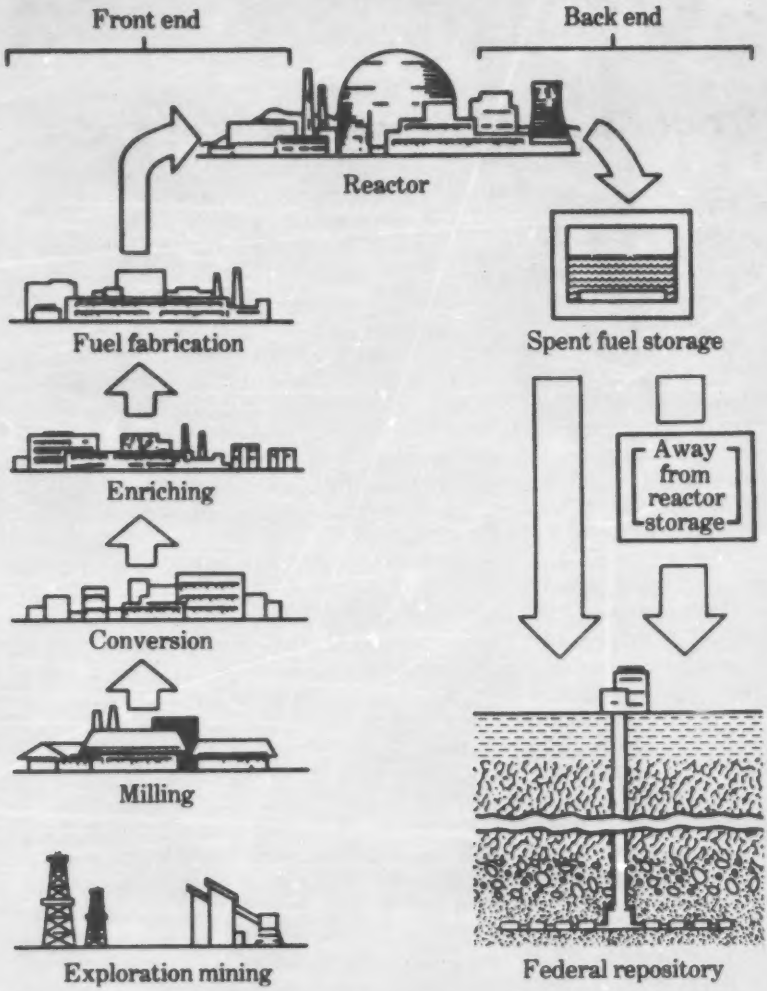
Uranium is mined in the United States and many other countries. In mills located near the mines, the ore is crushed, ground and chemically concentrated into yellowcake, a product that contains 70-90 percent uranium oxide. Yellowcake is shipped to plants that convert it into uranium hexafluoride, a gas. In this form the uranium is ready to be enriched at government-owned gaseous diffusion plants, to the richness of uranium-235 required to sustain a chain reaction. Uranium hexafluoride is filtered thousands of times through porous metal, with the lighter uranium-235 atoms becoming more concentrated with each pass-through, up to the desired 3 percent. The "depleted" by-product of the process, uranium-238, is stored at the enrichment plants for possible future use in breeder reactors.

The 3-percent product is converted into uranium dioxide powder and formed at private fuel fabrication plants into ceramic pellets slightly larger than a pencil eraser. These pellets are stacked end-to-end in a slender zirconium alloy tube about 10 feet long—a fuel rod—dozens of which are connected together to form fuel assemblies. The assemblies are then inserted into reactor vessels to become the fuel core of a commercial nuclear power plant.

As the fuel fissions, transuranics and fission products accumulate in the reactor fuel; and the latter eventually reduce the efficiency of the fission process. At that point, the spent fuel rods are removed from the reactor and submerged in cooling water in on-site storage pools. Once the spent fuel cools, thermally as well as radioactively, it can be moved to other storage pools away from the reactor (AFR) site or placed directly in a permanent waste repository. This last step in the fuel cycle—a permanent waste disposal system—does not yet exist. The United States and other countries are considering burial of these wastes in deep geologic formations, but to date no permanent facilities have been built. (See Resources: *A Nuclear Waste Primer.*)

Compared to possible alternative fuel cycles, the once-through uranium fuel cycle is relatively inefficient in its use of uranium. Indeed,

Figure 6: LWR once-through fuel cycle



proponents of other processes call it the throwaway cycle. A 1,000 MW nuclear power plant requires about 6,000 tons of uranium oxide for its 30-year lifetime. Modest improvements in fuels and reactor operating methods, now being tested here and elsewhere, can reduce these requirements by about 20 percent. Other improvements in reactor design can produce another 10-percent savings for a total of 30 percent. A more efficient enrichment process could bring aggregate savings of up to 50 percent. In comparison, however, the plutonium fuel cycle with breeder reactors has the potential of providing a 98-percent savings in uranium consumption.

Plutonium fuel cycle

The plutonium fuel cycle (Figure 7) could be used for LWRs. If it were, the front end of the cycle would be similar to that for once-through uranium. There would be, however, a distinct difference in the handling of spent fuel. Instead of being placed in a waste repository, the spent fuel would be sent to a reprocessing plant where usable uranium and the plutonium that was created by the reaction process would be recovered, then sent to a refabrication plant to be recycled into commercial fuel. The new fuel, called mixed oxide (MOX), would contain a mixture of uranium and plutonium oxides (not just uranium oxide as in present LWR fuel). This cycle could be repeated *ad infinitum*.

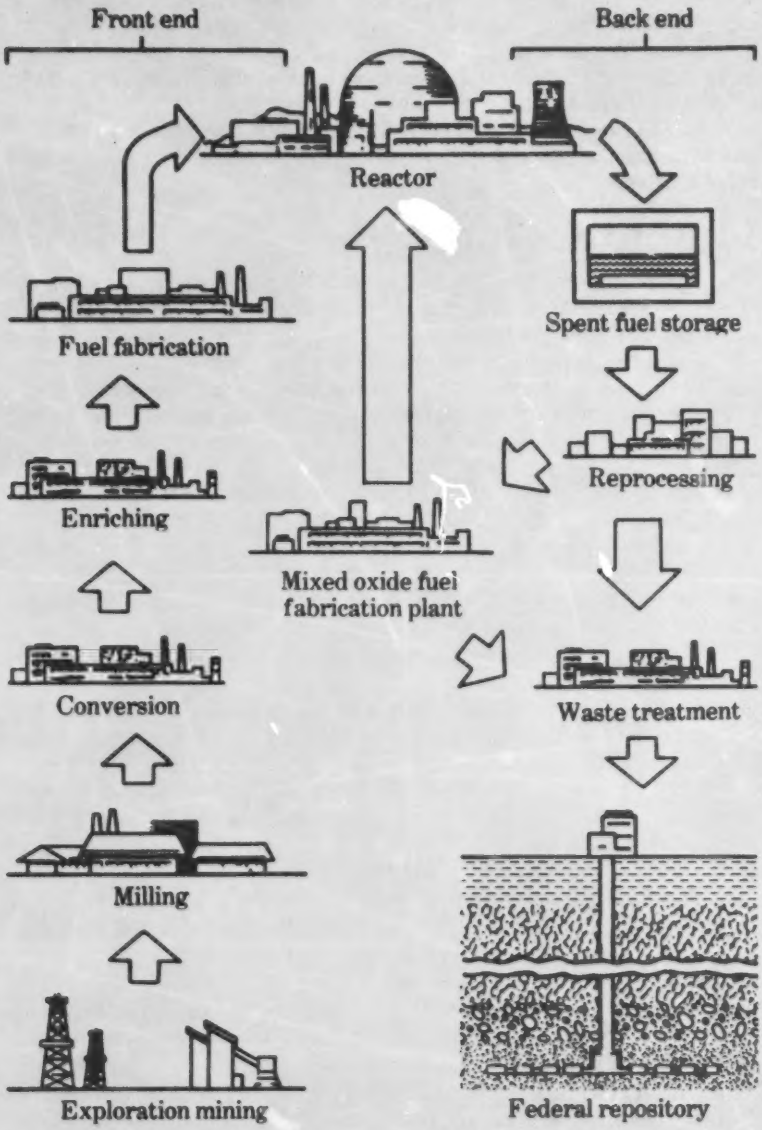
The waste products left over from the reprocessing operation—solids, liquids and gases—would then require chemical and physical treatment. The most radioactive portions would eventually have to be encased in special glass or ceramic for permanent disposal.

This plutonium fuel cycle could also service breeder reactors (Figure 8) with these differences.

- The plutonium and uranium recovered in spent fuel reprocessing would be sent to a *mixed oxide fuel fabrication plant*, which would prepare a MOX fuel with a higher concentration of plutonium than an LWR would use. It would also generate wastes that would have to undergo essentially the same treatment and disposal as wastes from reprocessing plants.
- A *blanket fabrication plant* would use the depleted uranium (uranium-238) left over from the enrichment process to make a fuel blanket that surrounds the MOX fuel in the core of the breeder reactor (see box: Nuclear Reactors: A Short Course).
- The *breeder reactor* would use the uranium-238 and MOX fuel to produce electricity. After a few years, the fuel would be removed and sent to a reprocessing plant to recover the plutonium and other fissionable materials bred in the reactor.

It is predicted that the plutonium fuel cycle could reduce the lifetime uranium requirements of an LWR by as much as one-third—from 6,000 to 4,000 tons—about the same level of efficiency as is projected from the

Figure 7 : Plutonium fuel cycle for LWRs



■ Readily accessible plutonium usable in weapons on short lead-time.

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use of uranium in an "improved" (advanced) once-through cycle. However, a breeder of equal size requires less than 200 tons over the same 30-year period. Furthermore, there is already in storage enough uranium-238 left over from the enrichment process for today's LWR technology to fuel a large breeder economy for centuries without any further uranium mining. Thus, from a resource-supply point of view, the use of breeders is the most attractive version of the plutonium fuel cycle for most countries.

How do the uranium and plutonium fuel cycles compare?

Beginning with the Ford administration, a number of studies have examined how once-through uranium and its offspring, plutonium, compare as sources of nuclear energy. These include:

- the CONAES Report (Committee on Nuclear and Alternative Energy Systems) of the National Academy of Sciences, *Energy in Transition, 1985-2010;*
- DOE's NASAP (Non-proliferation Alternative Systems Assessment Program) study;
- the INFCE (International Nuclear Fuel Cycle Evaluation) study; and
- a series of reports commissioned by the Department of State and conducted by Pan Heuristics, a private consulting firm.

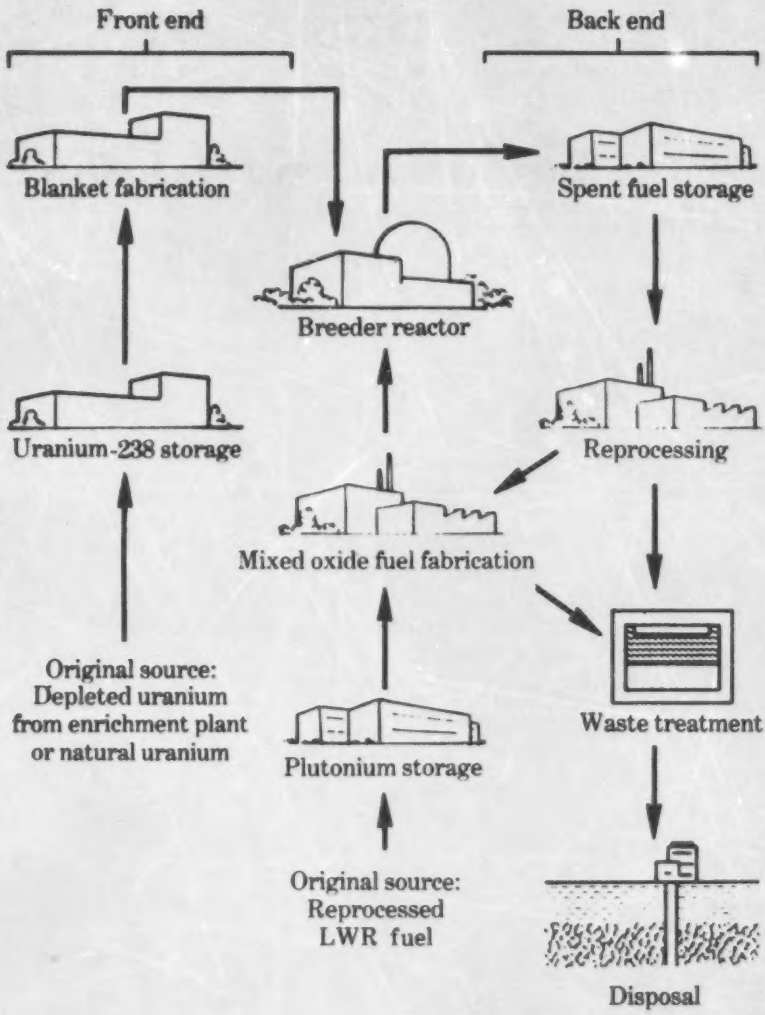
The major findings of these studies are grouped below under three headings: economics, energy security and waste management. (The Pan Heuristics study is quoted most frequently because, as the most recent, it expanded on the findings of the three earlier studies).

Economics

Since plutonium and uranium both serve the same function—to generate electricity—their relative costs are a major consideration in choosing between them. Most observers would agree that in the short term uranium fuels are less expensive than plutonium fuels. The cost of uranium oxide, which consists chiefly of exploration, mining, enrichment and fabrication, was only about $25 per pound in 1981, its lowest real cost in some seven years.

But what about the future? As the richest sources are mined out, the price will have to rise to make it economic to mine the lower-grade ores (see box: U.S. Uranium: Will It Last?). Rising prices would make more efficient LWR technologies and enrichment operations and technologies economically feasible and attractive. For example, DOE estimates that new technologies now being developed could reduce the cost of enrichment by more than half. The NASAP study found that the use of

Figure 8: Breeder reactor fuel cycle



■ Readily accessible plutonium, usable in weapons on short lead-time.

unreprocessed uranium fuels in breeder-type reactors (see fast reactor in box: Nuclear Reactors: A Short Course) could potentially cut uranium consumption by more than 90 percent.[1]

Plutonium fuel costs for use in LWRs compare unfavorably. Its costs lie chiefly in reprocessing spent LWR fuel and refabricating fresh fuel. The nuclear material recovered from the spent fuel would reduce the amount of additional uranium that would have to be mined and enriched. The greatest expense would be the construction of a large facility to reprocess and refabricate the fuel—a cost of $2 to $3 billion. This means spending $200 to $500 to reprocess a pound of spent LWR fuel to recover uranium and plutonium worth less than $100 at today's prices. Clearly, the price of uranium must rise substantially—by at least a factor of 2 to 5—before reprocessing/recycling in LWRs becomes economical. Even then, it is unlikely that reprocessing/recycling could reduce the cost of nuclear electricity by more than a few percent.[2]

Plutonium fuel costs for breeder reactors, on the other hand, present a different picture. While the cost of constructing and operating a reprocessing/refabrication facility would be somewhat greater, there would be no further need to mine or, for that matter, enrich uranium, since the breeder can use the depleted uranium left over from past enrichment operations for a long time. While the fuel cost picture is rosy, the high capital cost of constructing a breeder reactor is a counterbalancing factor. France, the country most advanced in demonstrating breeder reactor technology, estimates this would be some 75 percent higher than the capital cost of an LWR of comparable capacity.[3]

Given the difficulties that electric utilities are encountering in financing the current generation of LWRs, the price of uranium and alternative fuels—coal, oil and natural gas—would have to rise dramatically to justify the extra outlays for a breeder reactor. Estimates suggest that current uranium prices would need to multiply more than ten times—to $300-$400 per pound—before breeder reactors would become economical.[4] The Pan Heuristics study concludes that breeder reactors would probably not be economical before the year 2030.[5]

What has been discussed so far is the direct (out-of-pocket) cost of the uranium and/or plutonium fuel cycles to the electric utilities and their customers. The taxpayer would have to bear the additional costs of research and development, costs that could range anywhere from several hundred million dollars for LWR improvements to some $20 billion to bring the breeder reactor to the stage of being ready to go commercial.

Energy security

The United States is rich in uranium resources and has so far produced virtually all of the uranium it has consumed. Other countries, especially Japan and some European countries that depend mostly on imports, are acutely aware of their vulnerability to cutoffs. Consequently, they have

U.S. uranium: Will it last?

Are uranium supplies sufficient for the long-term future? The answer depends upon many factors, including the amount and price of uranium reserves, the future demand for nuclear power and the uranium efficiency of the nuclear fuel cycle.

Each year, DOE has published estimates of conventional U.S. uranium resources in two major groupings:

- the high-confidence categories: "reserves" (known to exist and believed by industry to be producible at a specific price) and "probable" resources (estimated to occur in known productive uranium areas);
- more uncertain resources: the "possible" and "speculative" categories in which the presence and cost of uranium is based on geological evidence and inference.[6]

DOE's 1980 estimate of U.S. nuclear capacity projects a high of 350,000 MW in the year 2020—a level that would require 3 million tons of uranium oxide for the life of the LWRs installed to that time.[7] With advanced technology, only two million tons would be needed.

Figure 9 presents the median estimates of uranium available at different price ranges. Uranium has averaged $30-$60 a pound between 1974 and 1980 (although the price fell below this range in 1981). In this price range, available resources using present LWR technology would not support the high DOE projection for 2020. But rising prices could produce more uranium oxide, not only from conventional sources but from phosphate, shale and seawater.[8]

The upshot is that the uranium resources to support a large nuclear industry well into the next century are there—at a price. Is it a competitive price? That depends on the future costs of alternative energy sources.

Figure 9: Uranium supplies

Uranium oxide price (1980 dollars) per pound	Uranium resources (millions of tons) High confidence*	High confidence* & uncertain
$30-$60	1.8	2.5
$60-$100	2.7	3.8
$100-$200	3.5	5.2
$200-$400	5.4	8.5

*includes 0.3 million tons of unconventional uranium oxide produced as a by-product of the phosphate industry through the lifetime of reactors on line in 2020.

Source: *An Assessment Report on Uranium in the United States of America*, Report GJO-111(80), 1980.

a strong interest in the plutonium fuel cycle as insurance against loss of uranium supplies. The question is: Can the use of plutonium be an effective means of achieving nuclear energy security?

The Pan Heuristics study looked at six countries (United States, United Kingdom, West Germany, Japan, South Korea and Brazil) and concluded that—at least prior to 2025—plutonium's contribution to energy security could be only minimal. In a "worst case" uranium supply interruption, plutonium fuels in LWRs could replace no more than 4 percent of the pre-interruption electricity supply and in breeders, no more than 1 percent.[9] Why? Because nuclear energy will supply such a small percentage of overall electricity production in those countries before 2025, and commercializing reprocessing and breeder reactors requires long lead times.

This study concludes that over the next several decades the most economical way for a country to achieve nuclear energy security is to stockpile uranium—just as the U.S. government has stockpiled minerals for many years. To illustrate, $900 million (the capital cost difference between a 1,000 MW breeder reactor and the same size LWR) spent on uranium at present prices could buy enough to fuel a current-design LWR for 75 years—2½ reactor lifetimes. Moreover, the nuclear energy security would be immediate, not decades in the future, and for all nuclear reactors, not just the reactors geared to plutonium fuels. At present, most uranium-importing nations do have modest stockpile programs.

Nuclear waste management

Virtually all major studies agree that from the point of view of safe nuclear waste management there is no substantial distinction between the uranium and plutonium fuel cycles. Both cycles would generate wastes that are initially about equal in radioactivity.

The chief waste resulting from the once-through uranium fuel cycle is spent fuel. The waste from the plutonium fuel cycle would be solidified high-level waste containing fission products—plus spent fuel cladding, transuranic wastes and other highly radioactive materials recovered or contaminated in the reprocessing/refabrication operations.

It is sometimes asserted that the plutonium fuel cycle would simplify the waste management process since the volume of solidified high-level waste would be less than 20 percent of the volume of spent fuel. However, when one takes into account the other materials that must be disposed of in a plutonium fuel cycle, the volume of waste—even after the best compaction technology is employed—rises several fold above the volume of spent fuel.

A more important consideration than volume is the heat generated by these wastes. Since high-level radioactive wastes generate heat for thousands of years, they must be packed in canisters that are carefully spaced in a repository to prevent overheating. On the criterion of annual

waste heat generated per megawatt of electricity produced, there is only a four-percent difference between the uranium and plutonium fuel cycles—with the uranium fuel cycle generating slightly less heat in its nuclear waste.[10]

U.S. policies

As indicated earlier, Ford and Carter administrations deferred making commitments to the plutonium fuel cycle for the following reasons: (1) plutonium fuels pose proliferation hazards, (2) the use of plutonium fuels does not result in a clear economic advantage in the near term, and (3) the United States should set an example of restraint to encourage other countries to exercise similar restraint.

As part of this policy, the Carter administration:

- imposed a moratorium on commercial reprocessing;
- suspended construction of the Clinch River (Tennessee) breeder reactor, a $3 billion breeder demonstration facility (although Congress never agreed to terminate the project completely); and
- funded several programs to develop an advanced once-through uranium fuel cycle as an alternative to the plutonium cycle.

The Reagan administration, however, is moving in the opposite direction. It has lifted the ban on commercial reprocessing, has initially proposed its largest nonmilitary budget increase for the Clinch River Project and has planned to phase out DOE research to improve the uranium efficiency of the LWR.

To provide a stable market for the commercial reprocessing of spent fuel, Reagan officials are exploring the feasibility of having DOE buy plutonium from the private sector for use in the breeder program. Some have also proposed that the Defense Department purchase this plutonium for use in nuclear weapons. Arms control advocates, however, have objected to this second proposal on the grounds that to breach the distinction between civilian and military nuclear programs, the basis of the Atoms for Peace Program, is to invite other countries to do the same. Proliferation concerns are discussed in more detail in the next chapter.

For the near future, the United States and other countries will continue to rely on the once-through uranium fuel cycle. It is not at all clear how soon and to what degree countries will develop the plutonium fuel cycle. □

7
Proliferation: The weapons connection

To what extent does the development of nuclear power on an international scale increase the risk of nuclear war? During the past decade, the United States has expressed increasing concern over the proliferation risk associated with nuclear power, citing reasons that fall mainly under two headings.

- By 1985, 25 nonweapon countries will have nuclear power reactors in operation, most generating enough plutonium to manufacture a score or more bombs annually if a country chose to separate it from the spent fuel. More important, some of these countries do in fact plan to build reprocessing facilities that will enable them to extract the plutonium from spent fuel. Other countries have or are building enrichment plants that could be used to enrich uranium to bomb-grade levels.
- Several countries attempting to expand their civilian nuclear industry are in the world's most politically volatile regions—the Middle East and South Asia. These include Israel, Libya, Iraq, Pakistan and India. Furthermore, some of these countries have acquired or are seeking nuclear weapons because they feel threatened by their neighbors. Wars have broken out in these regions every few years, and the introduction of nuclear weapons into these wars could result in millions of additional deaths.

While most experts agree that commercial nuclear materials and facilities could be diverted for weapons development, they disagree on just how likely this is to occur. The controversy centers around two basic questions: Are commercial nuclear fuel cycle materials usable in the manufacture of nuclear weapons? Are there cheaper and easier routes to nuclear weapons than the use of the commercial nuclear power programs, thus rendering concern about the weapons link pointless?

Commercial nuclear fuels: Are they suitable for weapons?

The short answer to the first question is yes. But there has been

confusion because the "best" plutonium for nuclear weapons is an almost pure plutonium-239 isotope. The plutonium-239 in commercial nuclear fuel is not pure because it is contaminated with other isotopes.

In the mid-seventies, a U.S. government weapons lab that reviewed this question concluded that all plutonium isotopes, even those created through long use in power plant reactors, are weapons usable and can reliably produce a nuclear yield in the kiloton range (a kiloton is the explosive yield of one thousand tons of TNT). In fact, the United States has exploded at least one nuclear device employing plutonium of the isotopic composition found in spent LWR fuel. Fuel can, of course, be removed from a nuclear reactor while the burn-up and therefore the level of contamination is still low. Finally, breeder reactors would produce plutonium with a much higher concentration of plutonium-239 than LWRs.

Alternative routes to weapons development

The answer to the second question is more complicated.

A country wanting to develop nuclear weapons can take one of three routes.

- It can build "dedicated" facilities, especially designed to produce weapons materials, as the United States and others have done.
- It can develop a nuclear power program based on the once-through uranium fuel cycle.
- It can develop a nuclear power program based on the plutonium fuel cycle.

The route chosen would depend on cost, ease of access to the technology, time required and the number of nuclear weapons desired. (Of course, a country can develop a nuclear power program without any intention of producing weapons.)

In general, the first approach is quicker and less costly than the other two. With a few years' effort and hundreds of millions of dollars, a moderately sophisticated country could build, first, a small reactor not intended to produce electricity but designed solely to create plutonium and, second, a reprocessing plant to recover the plutonium for nuclear weapons. Or for a comparable investment of time and money, it could construct a small enrichment plant and produce highly enriched uranium for weapons. In contrast, commercial power reactors, reprocessing and enrichment plants would cost billions and require as long as 10 years to construct.

The dedicated-facilities approach cuts total costs but increases risk. If other countries discover that a nation has gone this route, they may take diplomatic or even military action to halt the program. For instance, in June 1981, Israel did bomb and destroy an Iraqi research reactor because it believed that Iraq was planning to use the reactor to produce

plutonium for nuclear weapons.

On the other hand, commercial nuclear power programs—or, more explicity, the reprocessing or enrichment facilities linked to them—can supply the option to develop nuclear weapons without the specific commitment. Thus, a country could embark on a nuclear power program with no intention of developing weapons but, should its intentions change later on, it would have most of the needed ingredients on hand. It could become a member of the nuclear weapons club at small additional costs and in short order. How short depends partly on which fuel cycle it used.

Highly enriched uranium and separated plutonium are not normally present in the once-through uranium fuel cycle. Most nonweapons countries have no enrichment plants. They depend on nations such as the United States, France or the Soviet Union to supply them with low-enriched uranium fuel for their LWRs. Nations that do have enrichment facilities can upgrade them to produce highly enriched uranium. Several enrichment processes currently being introduced promise to be both cheaper and quicker to convert than the gaseous diffusion enrichment plants now in use. If they become widely available, they could provide an attractive route to weapons development in the future. Another option would be to construct clandestinely a small reprocessing plant and divert spent fuel from LWRs to this facility. But this approach would require almost as much time as building dedicated facilities and would involve the same risk of detection and censure by other nations.

In contrast to the once-through uranium fuel cycle, weapons-usable material is present (see Figures 7 and 8) in the plutonium fuel cycle. The material in fresh plutonium fuels and in reprocessing plants can be readied for use in nuclear weapons in less than a week. In fact, fresh breeder reactor fuel has such a high concentration of plutonium that fuel pellets can be used to make a nuclear explosive without any further chemical processing.[1] Each breeder reactor contains in its annual fresh fuel reload enough plutonium for hundreds of nuclear weapons. Thus, a plutonium fuel cycle could provide a nation with far quicker access to bomb material and the potential to develop a much larger nuclear arsenal than the once-through uranium fuel cycle.

To summarize, a nuclear power program, especially one using the plutonium fuel cycle, can give a nation:

- access to weapons-relevant technology;
- a cover for weapons research;
- a commercial activity to pay most of the cost of a weapons program;
- a variety of physical sites from which weapons-usable material can be diverted; and
- the potential for developing large numbers of nuclear weapons quickly.

The route chosen

To date, no country has used (commercial) nuclear power plants or materials to make nuclear weapons. The United States, the Soviet Union and China used the dedicated facilities approach to develop nuclear arsenals; their weapons programs have had no connection with civilian nuclear power. France and the United Kingdom also built dedicated facilities, but each gained access to the underlying technology through a joint military and civilian research and development program on nuclear energy.

India's recent entry into the weapons club was much more closely tied to its civilian nuclear power program. To make its first nuclear explosive, India used plutonium produced in a research reactor and recovered in a pilot reprocessing plant that was built to support the development of nuclear power and other peaceful uses of nuclear

Proliferation: It could be much worse

The nuclear weapons club now consists of only six countries—the United States, the Soviet Union, France, United Kingdom, China and India (just barely). What would be the implications for world peace and stability if Pakistan, Iraq, Libya, Israel and other nations seeking nuclear weapons openly joined this club?

First, the acquisition of nuclear weapons by even one more country could trigger the spread of these weapons into other nations in an international chain reaction. For example, if South Africa gets the bomb, Nigeria will want it. If Iraq gets the bomb, Saudi Arabia and Syria will want it.

Second, nations with only a few nuclear weapons may be more likely to use these weapons than countries with large nuclear arsenals. The United States and the Soviet Union have spent hundreds of billions of dollars to develop large nuclear forces that cannot be knocked out in a surprise attack. Small nuclear forces are not likely to be so "survivable." Consequently, a nation with a small, vulnerable nuclear force may feel the need to make a first strike in a crisis—quickly driving a localized conflict to high levels of destruction.

Third, most of the countries now seeking a nuclear weapons capability are politically unstable; they have a history of military takeovers or other internal crises. It is conceivable that mutinous military forces or terrorist bands in these countries could get their hands on nuclear weapons, use them to threaten or destroy the existing government, and kill hundreds of thousands of people in the process.

Fourth, small nations that acquire nuclear weapons could eventually develop the technology (e.g., missile systems) to deliver these weapons to distant parts of the world, broadening the stage for nuclear conflict.

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energy. Thus, while India did not use a (commercial) nuclear power plant to make this explosive, it did use *civilian* nuclear facilities.

Other countries have or plan to start civilian nuclear power programs that could be turned to weapons applications. Israel has a research reactor designed to support civilian nuclear research but capable of producing plutonium. (In fact, political analysts generally contend that Israel has already manufactured nuclear weapons.) Iraq plans to rebuild its research reactor and has a facility capable of some level of plutonium reprocessing; but how it will use these facilities is still not clear, since it has yet to buy a nuclear power plant. Pakistan is attempting to acquire both a uranium enrichment plant and a reprocessing plant; however, its one nuclear power plant does not require an enrichment facility, and reprocessing would be especially uneconomical for a program of Pakistan's size and fuel characteristics. South Africa is beginning to operate a commercial enrichment plant that might have weapons applications. Argentina, Brazil and other countries are also interested in obtaining reprocessing and/or enrichment facilities as part of their civilian nuclear power programs.

Thus, there is concern that while dedicated facilities have been the chosen route to nuclear weapons in the past, civilian nuclear programs may become an attractive route in the future.

Measures to control proliferation

The recognition of this fact has led the United States and other countries to seek out ways to guard against the use of nuclear power programs to develop nuclear weapons. Under the Non-Proliferation Treaty (NPT) of 1968, weapons states agreed to help nonweapons states develop civilian nuclear power programs if they placed all their nuclear activities under a system of safeguards administered by the International Atomic Energy Agency (IAEA). Such NPT parties Must:

.submit designs for nuclear facilities to the IAEA upon request to check their potential use in weapons programs;

.maintain accurate accounting of nuclear materials open to IAEA perusal, to ensure that uranium and plutonium are not being diverted to weapons development; and

.allow inspection of nuclear facilities by IAEA officials to verify that they are being used for peaceful purposes only.

Most countries' nuclear energy activities are operated under IAEA safeguards.

How effective are IAEA safeguards? The verdict is mixed. In the first place, a "safeguards" system acts not an an absolute barrier, but more like a burglar alarm designed to deter international violations by the threat of early detection. Some covert activities are easier to detect than others.

Inspectors can periodically count the number of spent fuel assemblies being stored at a nuclear reactor to verify that none of this fuel is being diverted. On the other hand, there is no accounting procedure that enables inspectors to determine, with zero error, the amount of plutonium in a reprocessing plant. A nation operating a reprocessing plant could divert some percentage of that plant's plutonium—enough for a "few" bombs per year—to weapons use without detection by international inspectors.

Another weakness is that IAEA safeguards cover only facilities and materials declared by the inspected nation. For NPT parties, this is supposed to include all materials more refined than natural uranium oxide and all facilities containing these materials. The aftermath of the Israeli raid on Iraq revealed that IAEA rules allowed Iraq to amass large amounts of natural uranium oxide (especially suitable for producing plutonium) and to acquire a facility capable of reprocessing—both of which were not yet safeguarded. Furthermore, the NPT and IAEA rules would have allowed Iraq to produce and separate plutonium as long as the activity was subject to safeguard inspections.

IAEA critics also cite the infrequency of inspections. Most are made only at intervals of several months; yet, a country using plutonium fuels or otherwise possessing plutonium could divert this material and fabricate it into weapons within a week.

While the IAEA safeguard system may be flawed, several international leaders would argue that the system has been an effective barrier against weapons proliferation. To date, no NPT parties have developed nuclear weapons from commercial nuclear facilities and materials.

The IAEA safeguard system is not the only tool available to control proliferation. Other management and institutional measures for making nuclear power more proliferation resistant are discussed below.

"Technical fixes"

Of the fuel cycles now available, the once-through uranium fuel cycle is the most proliferation resistant because it does not use or produce materials that can be quickly made into nuclear weapons. The United States has therefore considered developing more efficient LWRs and enrichment processes, so that they would be attractive alternatives to other fuel cycles that lend themselves more readily to weapons production.

As for the plutonium fuel cycle, scientists have studied the possibility of "denaturing" plutonium, that is, mixing it with other substances that render it unfit as weapons material. No effective version of this idea has yet emerged.

Scientists have had more success "denaturing" uranium-233, another man-made fissionable isotope that can be used as fuel in both LWRs and breeders. By mixing uranium-233 with uranium-238, this fuel can be rendered unfit for weapons use. Thus, the uranium-233 cycle is an alternative that would be less of a proliferation hazard than the plutonium fuel cycle.

Export restrictions

After several years of intense negotiations, major nuclear suppliers finally agreed in 1977 on common rules for the transfer of nuclear materials and technology. Of particular significance is the rule that any country buying certain nuclear materials and equipment must place these items under IAEA safeguards. Suppliers also agreed to exercise restraint in the transfer of "sensitive" technologies, such as enrichment and reprocessing plants.

Over and above this agreement, many countries have developed their own restrictive export policies, among which that of the United States is one of the most severe. It prohibits transfer of all reprocessing and enrichment technology. Furthermore, the United States will not export nuclear fuel or equipment unless the recipient country agrees to allow international inspection of all its peaceful nuclear activities. In comparison, some supplier countries require IAEA safeguards only on the nuclear material and equipment they have exported.

Domestic restraint

If a country believes a nuclear technology poses a significant proliferation hazard, it can refrain from developing this technology and call on other nations to exercise similar restraint. Of course, domestic restraint is likely to have the greatest impact if it is exercised by a major nuclear power. To date, the United States is the only major country to have used this approach (see box: The U.S. Example: Does it Count?).

Strengthening the NPT

Besides requiring nonweapons states to accept IAEA safeguards on all their nuclear activities, the Non-Proliferation Treaty requires weapons states to work toward nuclear disarmament, nonweapons states not to acquire nuclear weapons and all parties to cooperate in developing nuclear energy for peaceful purposes.

Three nuclear weapons states, the United States, the Soviet Union and the United Kingdom, and 111 other states have ratified the NPT. Two nuclear weapons states, France and China, and two states in a borderline status, India and Israel, have not. Several states with significant existing or potential nuclear capabilities—Argentina, Brazil, Pakistan, South Africa and Spain—have also chosen not to ratify the NPT.

Numerous measures could strengthen the NPT:

- inducing more countries to ratify the treaty;
- tightening the safeguard agreements negotiated between IAEA and nonweapons state parties;
- funding more inspectors to enforce the safeguards;
- adding sanctions to be imposed on violators;

- getting nonweapons state suppliers of nuclear technology to adopt the same restraints as weapons state suppliers;
- bringing the behavior of parties into line with the spirit of the nonproliferation provisions of the treaty (that is, having them show restraint in the trade of sensitive technologies that bring nations close to nuclear weapons).

The U.S. example: Does it count?

How effective has the U.S. example of restraint been? It is difficult to show cause and effect in international relations, but it is possible to compare "before" and "after." Before the Ford/Carter deferral of the commercialization of the plutonium fuel cycle, most major nations planned to commercialize the use of plutonium fuels in LWRs by the 1980s and breeder reactors by the 1980s or 1990s. Where do they stand now?

England has no plans for plutonium recycle in present generating reactors, and the completion date of a reprocessing plant has slipped from 1986 to 1990. It will defer until at least 1985 the decision on whether to build a breeder demonstration plant.

France has the most advanced program for commercializing plutonium fuels. It has a reprocessing plant and the world's largest breeder reactor under construction. However, it has no plans to recycle plutonium in LWRs and has deferred until the mid-1980s any decision on whether to construct commercial breeder reactors. The newly elected Socialist Party has urged a major slow-down in the breeder program.

West Germany has no plans for plutonium recycle in LWRs and has deferred plans for a large reprocessing plant because of public opposition. A small breeder reactor demonstration project has been under construction for many years but may not be completed because of a threefold increase in costs.

Japan has a small reprocessing facility for research and development programs. It plans to build a larger reprocessing plant but is having trouble finding a politically acceptable site. It has deferred use of plutonium fuels in LWRs but plans to begin construction this year on a small demonstration breeder reactor.

The Soviet Union, once a strong proponent of plutonium recycle, now says that the technology "is difficult to justify." Some Soviet authorities claim that breeder commercialization will not occur in the USSR before the 21st century.[2] The Soviets recently halved the size of their next planned breeder reactor.

Was it the U.S. example of restraint that affected these countries? Or was it the high cost of and public opposition to reprocessing plants and breeder reactors? Or was it a combination of factors?

What specifically could the United States do? Among the initiatives that have been suggested are the following: contribute expertise and money to achieve some of the measures noted above; refuse nuclear expertise and materials to nonsignatory nations; use U.S. influence to encourage other supplier nations to do the same; and upgrade efforts to make real progress toward nuclear disarmament.

Nuclear weapons-free zones

When adjoining countries form a nuclear free zone, they agree not to develop or acquire nuclear weapons. The 1967 Treaty of Tlateloco set up a nuclear-free zone in Latin America, but it was never ratified by all the countries involved. Nuclear-free zones have also been proposed for the Scandinavian countries, the Middle East, South Asia and Africa.

New international agreements and institutions

If countries had a reliable, secure supply of nuclear fuel for peaceful uses, they might feel less need to construct enrichment and reprocessing facilities. Three ways of assuring fuel supplies would be: to develop international guarantees (e.g., an agreement that when one supplier stops selling to an importer, the other suppliers would make up the deficiency); to create national fuel stockpiles dedicated to meeting specific emergencies; and to establish an international nuclear fuel bank that would supply fuel to a country whose normal source of supply had been interrupted.

Countries could also jointly build and operate spent fuel storage facilities, to reduce the tendency of each country to build up large inventories of spent fuel--a potential source of plutonium. The United States and Japan have discussed the possibility of establishing such a facility in the Pacific. Similar international depositories for "excess" stocks of plutonium, not needed for use in power or research programs, could be created, if the plutonium-based technology comes into use. An international agency such as IAEA could have legal custody over these depositories, a number of which could be kept small in order to keep weapons-usable material confined to a few locations. (There is no guarantee, however, that a nation using plutonium fuels would not divert plutonium for nonpeaceful uses while it is in transit to or from depositories.)

Finally, the most sensitive parts of the fuel cycle could be placed under international control. For instance, multinational operation of enrichment plants and reprocessing plants could help assure that these facilities were not misused for military purposes. Furthermore, locating these facilities in international fuel cycle centers would reduce the problem of surveillance. These facilities would still have proliferation hazards if they exported weapons-usable material to locations

Terrorism: Nuclear blackmail

The growth in terrorism is one of the more disturbing new social phenomena of the past decade. Not only are terrorist acts becoming more frequent, terrorists themselves have become more sophisticated and are organizing on an international scale. Some even have patron nations that fund their activities. For these reasons, there is concern that some terrorists may now have the resources and skills to penetrate nuclear compounds, steal nuclear materials and use these materials against society.

Various scenarios have been scripted. One pictures terrorists taking over a nuclear power plant or hijacking nuclear materials in transit, then blackmailing authorities into meeting their demands by threatening to release radioactive poisons into the environment.

Another postulates terrorist sabotage or bombing of nuclear power plants. Such terrorist activities might not succeed in breaching the many redundant safety systems that protect nuclear power plants; in fact, some nuclear facilities have already been bombed with relatively minor effects.

A third speculates that terrorists could steal weapons-usable material, either from a reprocessing-refabrication plant or in transit, and make a crude nuclear bomb. Since college students in the United States have used unclassified information to prepare detailed designs for nuclear weapons, it is likely that terrorists could do the same. Of course, terrorists would have to be able to fabricate the weapons without blowing themselves up—the fate of many an underground bomb maker.

Some experts believe that terrorists are not likely to use nuclear

under national control.

All these approaches suffer from the same major drawback: such agreements and institutions would require a degree of cooperation between nations that heretofore has been very difficult to achieve.

Frank discrimination

Since plutonium fuels present the toughest proliferation problems, nuclear weapons states or major industrial states could deny other nations access to these fuels. An even more discriminatory approach would be to deny plutonium fuels to certain nations that pose a "proliferation risk" or did not have a "legitimate need." This approach runs counter to the NPT, which entitles all participating countries to peaceful uses of nuclear energy "without discrimination" and commits the United States and many other nations to "facilitate the fullest possible exchange" of peaceful nuclear technology consistent with the overall purposes of the NPT.

explosives or poisons because they can find a dozen far easier ways to cause mass panic, disruption and death. This argument may be correct, but it is hard to imagine a more dramatic or terrifying threat than that of a nuclear weapon. If a nuclear bomb actually exploded in a city, it could kill over 100,000 people and contaminate a large land area.

What would the effects of nuclear terrorism be on our society? Some think that the worst effect might be that nuclear terrorism would force our country to adopt more characteristics of a police state. For example, in the event of a nuclear bomb scare, police might have to search large areas rapidly for nuclear devices, and civil liberties could suffer.

What precautions can society take against nuclear terrorism? Over and above normal surveillance of terrorists, a country could take the following measures to avoid nuclear blackmail.

- Set up tight security systems at nuclear facilities.
- Support the international agreement on the physical protection of nuclear materials that now exists.
- Upgrade the technology of physical security by building nuclear facilities and transport vehicles that would be more difficult to penetrate or sabotage.
- Select nuclear fuel cycles in which weapons-usable material is not present—for example, stay with the once-through cycle and convert research reactors to use low-enriched instead of highly enriched uranium.
- Rely on nonnuclear sources for commercial energy.

The proper U.S. role: What should it be?

The Ford and Carter administrations believed that the United States could exercise influence against proliferation through its position on exports of nuclear technology and through the character of its own nuclear energy program. This viewpoint rests on three premises. The first is that the U.S. share of the world nuclear export market is substantial enough to constitute leverage over other countries—both buyers and sellers. The second assumption is that the United States can influence nations that use our nuclear services, through persuasion and through exercise of political and economic incentives and disincentives. And the third assumption is that the United States is still a model that influences the behavior and aspirations of many other countries.

Critics of this viewpoint argue that all three premises are either outmoded or unsound. Some argue, further, that if the United States

wants to control proliferation, nuclear power is the wrong target. They contend that the desire for nuclear weapons exists independent of the desire for nuclear technology. Since driving forces behind proliferation are the regional hostilities, tensions and inequalities that lead to war, they argue, the spread of commercial nuclear power could actually help alleviate two sources of tension among nations—poverty and energy shortages.

The Reagan administration has indicated that it will rely more on broad political and diplomatic initiatives to prevent the spread of nuclear weapons than did the Carter administration and less on efforts at direct control of nuclear fuel and technology. Its nonproliferation policy will focus primarily on reducing the security concerns that motivate some nations to seek nuclear weapons capability, by supplying conventional arms or offering the protection of the U.S. nuclear umbrella.

President Reagan also wants to reestablish the United States as a predictable and reliable supplier of nuclear technology. To help achieve this goal, he has instructed the NRC to expedite action on nuclear export licenses. Some members of Congress have been highly critical of this initiative, charging that an aggressive nuclear commerce policy is what has enlarged the nuclear weapons club to its present membership.

While experts disagree on how significant the contribution to proliferation nuclear power makes or can make, most agree on one point: stopping the spread of nuclear power or limiting its evolution to forms considered more proliferation resistant cannot by themselves stop proliferation. Countries with sufficient determination can get bombs by other routes.

Those who nonetheless want to make nuclear power more proliferation resistant make these claims for the strategy: It can limit the number and size of nuclear weapons that nations can produce from commercial nuclear materials. It can increase the costs—both economic and political—of using this route to a level that few nations can afford. It can also buy time for slowing the spread of nuclear weapons (see box: Proliferation: It Could Be Much Worse). And national leaders can use this time to fashion institutions capable of deterring the use of nuclear weapons by however many nations possess them. □

8
Conclusion

The last five years have been trying ones for the U.S. nuclear power industry. The accident at TMI and government inertia on the nuclear waste disposal problem have eroded public support for nuclear power. Operating plants have been plagued by equipment problems. And utilities have had to cancel over a hundred orders for nuclear plants, as a result of decreasing demand for electricity and spiraling construction costs. Unless utilities start placing orders for nuclear power plants in the next few years, the nuclear industry could go under. The question is: Can nuclear power make a comeback?

At present, the political climate for nuclear power could hardly be better. The Reagan administration views nuclear power as one of the best potential sources of electrical energy. While federal funding for coal, solar, conservation and many other energy sources was slashed in fiscal 1982, the budget for nuclear power was left virtually intact. The investment climate for nuclear power got a boost when Congress passed tax legislation that will enable utilities to attract new capital for power plant construction. The Administration has also instructed agencies to streamline the nuclear power licensing process; to proceed with the commercialization of the breeder reactor; to encourage commercial reprocessing; to ease restrictions on nuclear exports; and to get going on the permanent storing and disposal of commercial high-level radioactive waste. All these initiatives are expected to breathe new life into the nuclear industry.

Congressional and public response to these initiatives has been mixed. Everyone agrees that solving the nuclear waste disposal problem is a worthy objective, despite disagreement over the best approach. The Administration would like to establish a demonstration nuclear waste disposal facility within a few years. Others prefer a comprehensive, step-by-step R & D program that would provide opportunities for extensive private-sector involvement and lead to a full-scale, licensed permanent geologic repository by the end of this decade.

The Administration has had a more difficult time mustering support for its breeder reactor and commercial reprocessing goals. Critics contend that the breeder does not make economic sense at this time because uranium is plentiful and the number of reactors expected to use it is diminishing. They also point out that there is really no market for reprocessing without the breeder program. Some have suggested that

federal R & D funds would be better spent on designing a safer and more efficient version of the LWR—one that could be standardized and more quickly licensed.

Still others argue that the government should spend less money on all nuclear R & D—that nuclear power should not get preferential treatment over coal, solar and other energy options. Supporters of the Administration program maintain that investments in the breeder and reprocessing are needed now to help ensure future energy supplies.

The Administration has not tackled other problems plaguing the nuclear industry. It has not taken an active role in the cleanup of the damaged TMI reactor, although some federal funds will be made available. Nor has it proposed new insurance programs. It expects utilities and nuclear vendors to take the lead on these issues.

For two decades, the federal government has been perceived to have the sole authority to regulate nuclear power. The state laws that have been passed limiting the siting of nuclear power plants and waste disposal facilities have been challenged in court. In October 1981, a federal appeals court ruled that a state does have an "inherent" power to prevent construction of nuclear plants "inconsistent with its need for power" or "with its environmental or other interests." If the Supreme Court chooses to review the appeals court ruling and upholds its decision, states could have a significant impact on whether nuclear power does make a comeback.

If states block nuclear construction or utilities fail to purchase new nuclear units or for other reasons nuclear power is unable to make a comeback, what would the impact of losing this energy option be? Economic conditions, demand for electricity and energy prices have changed so dramatically in recent years that it's virtually impossible to predict with any certainty just what the effects would be. Some have predicted that loss of the nuclear option will mean higher electricity costs, more pollution from coal-fired plants and less economic growth and social mobility. Others believe that demand for electricity will rise so slowly in coming years that reliance on improvements in energy efficiency and renewables will easily fill nuclear's niche in the nation's energy mix without disturbing social and economic growth.

Nuclear power was developed under a veil of secrecy; only a few scientists understood either the potential or the danger inherent in this technology. Thirty years later, the merits and demerits of nuclear power are being debated by all segments of society. However, what is being debated today is not primarily how this technology should be developed—a technical issue—but what type of commitment should be made—an economic and political, and even a moral issue. While scientists played a dominant role in the first decision, the public will shape the second through their decisions in the market place and the voting booth, and through their participation in energy policy making at the local, state and federal levels. □

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More LWVEF resources for citizens

For a wealth of resources, the reader is advised to scan the *Primer*'s lengthy *Notes* section. These books, pamphlets and reports, which explore and examine specific nuclear issues in greater detail, can give the interested citizen a more wide-ranging understanding of the subject.

The following list of League of Women Voters Education Fund (LWVEF) publications supplements the *Notes* section. All materials were written, like the *Primer*, in the unbiased, concise and easy-to-understand manner that is the trademark of the LWVEF. Two specifically deal with nuclear issues. Another, *Energy Brief 1*, supplies a list of nuclear-related publications. The rest focus in on the citizen's role in local and state government planning and operation—background information that's essential to grasping a total picture of your place in the nuclear power debate.

- *A Nuclear Waste Primer*, Pub. No. 391, 63 pp., 1980, $1.95.
- *Taking Nuclear Issues to the Village Square: A Guide for Community Leaders*, Pub. No. 155, 8 pp., 1981, 75¢.
- *Energy Brief 1: Nuclear Power: An Annotated Bibliography*, Pub. No. 466, 2 pp., 1981, 20¢.
- *The Citizen and the Budget Process*, Pub. No. 482, 20 pp., 1974, 75¢.
- *The Politics of Change*, Pub. No. 107, 16 pp., 1972, 75¢ (how to analyze the informal power structure in your community).
- *Anatomy of a Hearing*, Pub. No. 108, 12 pp., 1972, 60¢ (tips on how to testify).
- *Going to Court in the Public Interest*, Pub. No. 244, 16 pp., 1973, 25¢.
- *Simplified Parliamentary Procedure*, Pub. No. 138, 12 pp., 1979 revised edition, 30¢.